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ON THE PEPTIC DIGESTIBILITY OF SOME INFANT MILKS AND MILK MIXTURES IN VITRO

BY

HEIKKI KALLIALA

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HELSINKI, FINLAND

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PREFACE

I should like to take this opportunity of expressing my sincere gratitude to my highly respected teacher, Professor Arvo Ylppö, M.D., who suggested the theme for my thesis, and who followed the progress of the work with great interest and kind encouragement. Professor Ylppö very considerately put at my disposal the laboratory facilities of the Children's Hospital, thereby rendering valuable help to me in my investigations.

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INTRODUCTION

In Finland, the relative quantity of milk consumed by the population is greater than in most, if not all, European countries, especially if we consider the habits of the adult population. This, as well as an energetically applied legislation and appropriate sanitary measures, contributed to the very high standard of milk hygiene which prevailed in our country before the Second World War. This holds good especially for the commercial milk of the greater population centers.

The shortage of milk during and after the war impaired the situation in many ways. The lower quality of milk has certainly played a considerable part in the high frequency of severe infantile diarrhea during the years following the war. This is convincingly demonstrated in a recent paper (175).

It is evident that the Finnish pediatricians and the milk producers must together strive towards developing a safer milk at least for infant feeding purposes. The methods generally used for destroying the microbes of the milk or preventing their growth cause varying degrees of physical and/or chemical changes in the constituents of milk. These changes influence also the digestibility of milk, and this factor should also be considered in the planning together with the cost of processing etc. A study of the digestibility of certain milks and milk mixtures would thus seem to be of practical interest.

The only entirely adequate method of studying the order of preference of different formulas would, of course, be the performing of feeding experiments on healthy infants. This, however, meets unsurmountable difficulties. The adaptability of an entirely healthy infant is extraordinarily great. Both the history of pediatrics and the experience of the country practitioners even nowadays present plenty of evidence of children thriving excellently in spite of having been fed nearly from birth only on raw undiluted cow's milk which

we know to be a very unphysiological food for a young infant. An even more drastic example is a case (177) in which a child lived the first year of its life practically only on fish soup and fish, receiving no milk of any kind. Thus, only the health and development of the constitutionally weakest, the least adaptable individuals of each group could serve as an indicator of the suitability or non-suitability of the formulas to be tried out. This would require large experimental groups, in order to include a sufficient number of these »weak» individuals. The experimental subjects ought also to reside in the same institution simultaneously, in order to exclude the errors caused by factors of environment like hygiene, climate, quality and severity of threatening infections, etc. There scarcely exists a single published feeding experiment which would entirely meet the requirements listed above.

A much-used method is to feed the same infant alternately with the formulas in question, the periods being, e.g., 10 or 14 days. The gain in weight during the periods is considered to be an indicator. Of the weaknesses of this method the following may be mentioned: The longer the periods, the more the physiological capacities of the child change with the increasing age, from one period to another. The factors of environment can never remain entirely constant during the different periods. If the periods are short, the child's organism has not sufficient time to adapt itself to the new nutrition, and thus does not attain its optimal effectiveness. It must also be remembered that if we compare an »easily digestible» food A, which requires little effort of the organism, with another, B, which is »difficult of digestion», requiring, e.g., a copious secretion of digestive juices, it will probably be much easier for the child to change from B to A than from A to B. This must, of course, be considered when estimating the thriving of the child during the respective periods. Often it has been attempted to improve on the reliability of these investigations by performing, e.g., three or five day balance experiments. However, the results are rarely very significant because, as already mentioned, a healthy infant is capable of satisfying its nutritional needs, both quantitative and qualitative, while being on considerably differing diets.

We also know that, generally, the nitrogen, calcium and phosphorus retentions of the bottle-fed infant are greater than those of a breast-fed infant of the same age and weight (155, 85). But both a teleological conception and our clinical experience

require us to consider the healthy breast-fed child to be the normal standard. Thus we cannot hold that higher retention figures would be sufficient evidence for the greater excellence of a certain type of food.

It is also generally very difficult to evaluate exactly to what extent an increase of weight represents healthy, optimal growth, as opposed to overfattening or excessive water retention.

Feeding experiments on pairs of identical twins would theoretically approach the ideal. Of course, both twins should be originally of about the same weight. This kind of experimental subject is rarely available, but some experiments using this method have been published.

Animal experiments may no doubt be useful when the milks to be compared differ only slightly from each other (e.g., homogenized and non-homogenized milk). On the other hand we would not be justified in presuming that, for instance, the diluting of cow's milk would affect the digestion process of infants and young rats, respectively, in the same way and to the same degree. Still less may milks of different mammalian species be compared by this method.

There are also many sources of error in experiments *in vivo*, where samples of the stomach contents are examined after a certain time since the ingestion of milk. The amount of saliva mixing with the milk in question, the secretion of gastric juice and the rate of evacuation of the stomach may differ considerably from one experiment to another, and depend much on, e.g., psychical factors. In spite of every attempt at emptying the stomach completely, at least the casein curds exceeding the lumen of the catheter in diameter will remain. It is questionable whether they can be seen in a fluoroscopic control (this applies also to evacuation time investigations) if the amount is not considerably great.

The *in vitro* methods have naturally many weaknesses, too. In them, the secretion by degrees of the digestive juices, as well as the peristalsis, may be reproduced somehow, but it is hardly possible to imitate the evacuation of the stomach, taking place in small amounts and starting soon after the ingestion of food. It would, however, seem probable that by studying different milks and milk mixtures in circumstances which roughly correspond to those prevailing in an infant's digestive canal, a conception of their *relative* digestibility may be formed.

As already mentioned, the organism of a healthy infant is able to adapt itself even to fairly unphysiological diets, for which reason the utilization percentages do not differ much when different milks and milk mixtures are fed. It is, however, evident that there is greater stress on the organism, the more the properties of a certain milk differ from those of the natural food, i.e. human milk.

Clinical experience and experimenting have, during the last hundred years, led to the development of a great variety of formulas for infant feeding.

Different as they may be, there is one common feature in all successful milk modifications: they cause the casein of cow's milk to curdle in a finer and softer form than the coarse particles of untreated milk [Brennemann, (14)]. It is evident that the greater surface open to the action of enzymes must be favourable for the digestion. Also, the pylorus delays for long periods the passage of too big and too hard particles (21), although we know that even comparatively large foreign bodies like coins etc. finally leave the stomach by this way, as do often very great and hard casein curds (82). The textbooks seem to agree that the behaviour of the casein in the stomach is by far the most important among the factors which influence the digestibility of a milk or milk mixture.

The experimental method chosen for the present investigation imitates the action of an infant's stomach. An attempt is made to follow the decrease of the size of the curd particles and the increase of filterable nitrogen in these circumstances, using various milks and milk mixtures of practical importance in our country.

SURVEY OF THE LITERATURE

The literature concerning the feeding of infants and children is so extensive that not even the great handbooks on these questions (e.g., Czerny and Keller, 1925—1928) can attempt a complete reviewing. Therefore only a part of the more important papers will be mentioned. For the same reason, generally, only papers published after 1900 will be included.

The textbooks on physiology usually describe the gastric digestion approximately as follows: The different portions of swallowed food are stored in the antrum and fundus in the order of arrival, the first portion nearest to the pylorus. Secretion of pepsin and hydrochloric acid has often set in already at the sight and smell of food; if not, it starts some minutes after the deglutition of the first portion of food. Peristalsis also commences in some minutes; at first the waves are shallow and originate in the antrum. As the digestion proceeds, the peristaltic waves start farther up and ultimately originate near the cardia. At first they only transport matter liquefied by the action of gastric juice from the vicinity of the gastric wall. A thorough mixing of the different portions of food with each other and with gastric secretions occurs only at a late stage of the digestion.

This applies to the adult. The gastric function of the young infant differs from this picture, as both the motor force of the gastric wall and the amount of secreted hydrochloric acid and proteolytic enzymes are smaller. The different theories and findings concerning the rôle and significance of the stomach in the infant's digestive process will be briefly reviewed.

Further, a short review is given of different methods of treatment which influence the character of the casein curd of milk. Lastly, some earlier experiments on the digestibility of milk will be mentioned.

1. On the problem of the peptic digestion in infants

Pepsin or its precursor pepsinogen has been found by many authors in newborn babies and even in fetuses (for references, see 28, 149, 171). The presence of hydrochloric acid is also demonstrable already at birth and the acidity of the newborn's stomach often reaches notably high values (64, 81). During the first week of life it decreases, however, to *p*H values far from the optimum for pepsin. Accordingly, these has been much discussion as to whether there is any possibility of peptic digestion in the stomach of the young infant.

The earliest investigations were performed by titrating the »free HCl» and their significance in estimating the possibility of enzyme action is thus but small. The first to determine the hydrogen ion concentration was Allaria (2), who found values of about *p*H 5.3 and concluded that no considerable digestion of protein in an infant's stomach could take place. Only three of his subjects were entirely healthy, however.

Tobler (160) presented investigations performed on young dogs and cats and observations on a four-year old boy having a duodenal fistula. According to Tobler the curdling of milk in the stomach took place rapidly, in 10 to 15 minutes, whereupon the whey was evacuated through the pylorus; the remaining mass of casein and fat was then liquefied through the action of pepsin from the periphery. The weak peristalsis of the infant's stomach was not able to churn and mix the curd; the gastric juice had access to it only in a narrow zone along the walls. Thus the effect of the gastric juice in this zone would be comparatively great. In his opinion, one could not obtain a »representative» sample of the gastric contents through catheterization, because the acidity would depend on the distance from the wall that the aperture of the tube happened to be.

Davidsohn (29) and Salge (134) published values ranging mostly from *p*H 4 to *p*H 5. The optimum for pepsin being about *p*H 2, and *p*H 4 being considered as the limit of pepsin activity, they concluded that there is no peptic digestion in the infant's stomach. Accordingly, lipolysis was thought to be the most important function of the infant's stomach (30).

Tobler (162) argued that these low acidity values were a result of the acid border zone and the neutral middle zone having been mixed together; thus they would not represent the actual condi-

tions. He published determinations according to which the proportion of soluble to insoluble nitrogen had increased during digestion. Salge (135) proved that the acidity tended to increase as the age of the infant increased and regarded the presence of HCl and pepsin in the infant's stomach as being only a sign of a developing function (»Ausdruck einer werdender Funktion»). He, as well as Davidsohn (31, 32), stressed that Tobler's theory held good for raw cow's milk only, whereas the boiled and diluted mixtures used in infant feeding curdled forming rather fine flakes. As the whey, moreover, would not to any considerable extent leave the stomach separately, the gastric contents could be considered to be homogeneous. Schackwitz (136) found in healthy infants mostly values between *p*H 4 and *p*H 6, yet in one-third of the samples between *p*H 2 and *p*H 4, with great daily variations. Davidsohn (33) remarked that Schackwitz had used samples of 1 to 2 ml, wherefore they might in some instances come entirely from the sour zone close to the wall, the existence of which zone Davidsohn thus now accepts. His own new measurements on the entire gastric contents, gave values of about *p*H 5 with little spreading. Tobler's pupil Kronenberg (94) found values between *p*H 4 and *p*H 5. He performed *in vitro* experiments using an extract of the mucosa of infant's stomachs and found that while an acidity of at least *p*H 2.9 was necessary for the digestion of coagulated egg albumin, there was in milk even at *p*H 4 an increase of soluble nitrogen. Davidsohn in a review (34) restated that in an infant's stomach no peptic digestion was possible. While admitting an increase of soluble nitrogen in the stomach, he offered several explanations of how this might ensue without any pepsin activity. When first a small sample and then immediately the rest of the gastric contents were removed, the average difference in *p*H was 0.3, the greatest one 1.4 (35). Evidently the acidity differences between different parts of the gastric contents were not so big as presumed by Tobler. Investigating the effect of different milks Davidsohn found the following averages: $\frac{1}{3}$-cream milk: *p*H 5.07; $\frac{2}{3}$-milk: 4.87; albumin milk: 4.71; buttermilk: 4.28. The infants were from one to six months old. With whole milk, in six to 12 month old babies the *p*H was 5.57. The average for breast milk, including some values published by others, was 4.48. — In all papers quoted above, the sample was taken after $1\frac{1}{2}$ to 2 hours after the meal.

Babbott, Johnston, Haskins and Shohl (5) used a test-meal of

part-skimmed $^2/_3$-milk. After one hour, most values were between *p*H 3.9 and *p*H 4.6. After two hours, the average was 3.9. Marriott and Davidson (105, 106), using always the particular formula to which the infant was accustomed, found in healthy breast-fed babies $^3/_4$ of the values to lie between *p*H 3 and *p*H 4, the average being 3.75; in sick breast fed children the values were above 4; average: 4.74. With sweet cow's milk mixtures the averages were: previously breast-fed babies, 5.3; previously bottle fed infants, 4.75; sick infants 5.35. With lactic acid milk, the acidity was considerably higher: in healthy infants the average was *p*H 3.71, in sick, 4.1. Davison (36) tried to exclude samples where an admixture of saliva or duodenal juice might distort the results, by determining the amylase and trypsin activities. The children were bottle-fed and the samples taken relatively late. The average *p*H of the »pure» samples was 3.9 with sweet milk mixtures, 3.5 with acid milks. One four-month old infant, having been fed on undiluted, unsoured cow's milk for three months, even showed values around *p*H 3.3. The results quoted above led Marriott and Davidson to the conclusion that the gastric acid secretion adapted itself to the properties of the food. Demuth (40) found somewhat lover acidity values. The only kind of milk causing *p*H values below 4 was the albumin milk. It is to be noted especially that the acidity with breast milk was always lower than with even sweet cow's milk mixtures; the average during the first trimester of life was 5.94, during the second 4.97, and during the third 4.49. He also concluded that the stomach of an artificially fed infant may, in response to the greater buffer capacity of the food, increase its secretion of acid. The final acidity values may even be higher than those found with breast milk.

To sum up, it is evident from the literature quoted, that the acidity prevailing in the stomach of the healthy infant during the first two or three trimesters of life, i.e. the milk diet period proper, is not favourable to peptic activity. As best the splitting of protein through pepsin cannot occur to any great extent.

In the literature there are numerous and partly conflicting reports regarding the influence of sickness on gastric acidity. Schackwitz (136) found in sick infants both high and low values. Hainiss (65) using a »test-meal» of tea, found in dyspepsia very high acidity values, up to *p*H 2. The control values in healthy children were around *p*H 4. Davidsohn (35) found constantly high

*p*H values (low acidity) in »grippal» infections. Zahn (176) found that experimental exposure to heat and thirst decreased the secretion of both gastric juice and hydrochloric acid in dogs. Chievitz (24), like Marriott and Davidson (106, 107) found that both parenteral and gastroenteral infections, especially if of long duration, tended to lower the gastric acidity. Ylppö (174) demonstrated that experimental hyperthermia lowered the gastric acidity by about one *p*H-degree. The fever caused by smallpox vaccination seemed to have a similar effect. Demuth (40) found in »dyspepsias» varying but mostly increased acidity values, in dystrophia and infections low values.

Most of the results mentioned above, as well as many not quoted here, indicate that the ability of the infected child to secrete gastric juices is lowered and thus the possibility of effective peptic digestion is even smaller than in healthy children.

Numerous authorities (for lit., see 67) had shown that after a meal a reaction persists in the greatest part of the small intestine for several hours which is slightly acid, i.e. unfavourable for tryptic digestion. This called for new explanations as to how an infant could digest protein at all. Heller (67) proved that the presence of bile moves both the *p*H optimum and the limits of the effect of trypsin in the acid direction. Hoffman and Rosenbaum (74, 75, 76, 77, 78, 79) investigated the secretion of gastric juice by means of the »Magenzuckerkurve», i.e. determining the lactose content of the gastric contents after regular periods of time; the decrease of this content was held to be a measure of the secretion. According to them, breast milk and ⅓-milk would provoke little or no secretion of gastric juice, while milk mixtures of a higher protein content than that of breast milk would call forth a considerable secretion. Of the constituents of milk, practically casein alone (and, especially, the peptones produced from it through the action of pepsin) possessed this secretion-provoking effect. Even the buffer capacity did not seem to be of importance: a breast milk, brought up to the buffer capacity level of cow's milk through the addition of phosphate or citrate did not provoke a greater secretion than plain breast milk. Müller (115) found, however, that if the casein content of the food is high, the buffer capacity has an influence: the »gastric sugar curve» of lactic acid milk approaches that of breast milk while a strongly alkalized milk (*p*H 10.35) provokes a secretion which is even twice as great as with whole cow's milk. Thus,

also the acidity of the gastric contents has a regulating effect on the secretion. — By determining the increase of chlorine in the gastric contents, Hoffman and Rosenbaum found that the amount of gastric juice secreted during 1½ to 2 hours after a meal of breast milk was about 13% of the gastric contents; others (26, 142) found mean values of about 18%. It is evident that with breast milk, the secretion of gastric juice is relatively small. Undoubtedly, a considerable part of the increase of the gastric acidity, as compared with the original reaction found with this milk is due to a lipolysis, (8, 142, 54).

However, in several investigations it was found that gastric juice as such, without any addition of hydrochloric acid, possessed at least some proteolytic power. Gastric juice of infants broke up considerable amounts of casein at its natural *p*H (3—4), while egg and meat proteins were not affected (150, 66), Rosenbaum and Spiegel (131) took samples of the gastric contents 1½ hours after a meal, placed the samples in an incubator at 37° and determined the increase of soluble nitrogen. They found such an increase, often at a *p*H very unfavourable to pepsin action, with ½ milk and ⅔-milk but not with ⅓-milk and breast milk. This is well in accordance with the gastric secretion findings of Hoffman and Rosenbaum (see above). Hess (72), by the same technique, found an increase of soluble nitrogen also with breast milk and ⅓-milk. Budde (19) investigated this question thoroughly, determining the free carboxyl groups liberated through proteolysis (technique of Willstätter and Waldschmidt-Leitz). Experiments were performed both *in vivo* and *in vitro*, in the latter case with gastric juice obtained by means of a test meal of tea with sugar. In both cases a distinct proteolysis was noted, the optimum of which was around *p*H 3 when casein or milk were used as a substrate, but which went up to as much as *p*H 5. In identical circumstances, the digestion of albumin was only 30 to 40% of that of casein. The digestion of breast milk amounted to little more than one half of the digestion of cow's milk; this she explained by the higher albumin to casein ratio of the breast milk. Freudenberg and Buchs (56, 18) found that the gastric juice of infants contained considerable amounts of cathepsin, hitherto believed to be solely a tissue enzyme. Its acidity optimum, when cow's milk is used as a substrate, lies between *p*H 4 and *p*H 5. This finding thus explains the proteolysis found outside the range of pepsin by previously cited authorities. Mellan-

der (109) has also found proteolysis when the gastric juice of infants at *p*H values of 3.5 and 3.7 was allowed to act on pure breast milk and cow's milk casein, respectively. In identical circumstances the digestion of cow's milk casein proceeded two or three times as rapidly as that of breast milk casein.

To summarize, in spite of the low acidity of the infant's gastric contents, at least in healthy infants some amount of proteolysis occurs in the stomach. In breast-fed infants, however, the significance of this process is not great. It is well known that the casein curd of breast milk is very finely divided, so that even a curdled breast milk appears nearly homogeneous and the surface open to the attache of enzymes is large. On the other hand, it is probable that if the milk or milk mixture forms great solid curds, the pylorus will at least for some time keep them from passing through (21). When the rest of the gastric contents have been evacuated, they will be subjected to a more effective digestion in something of the way described by Tobler. The size of the biggest particle which might pass the pylorus without delay is not known, but it has been presumed to be about 1/12 of an inch (42). In the stools of infants fed with raw cow's milk, smooth, very solid, wax- or rubberlike curds may be found, the size of which may be compared to a finger joint (82). The fact that such curds may pass the entire intestine while undergoing only a slight digestion on the surface, itself demonstrates the significance of the size and texture of the curd particles for the digestibility of milk.

2. On the Evacuation Time for Different Kinds of Milk Diet

Towards the end of the last century it was already well known that an infant's stomach was evacuated much more rapidly after a feed of breast milk than after one of cow's milk. The X-ray technique has been widely used for determining the exact evacuation time after different kinds of food. Generally it has been presumed that a food which is rapidly evacuated is also »easily digestible». Tobler and Bogen (161) found that generally doubling the volume of the meal increased the evacuation time by one third to two thirds. A high fat content distinctly retarded the evacuation. If the volume of the meal was constant, a more diluted milk mixture was evacuated more rapidly; if the amount of milk was kept constant, the more diluted mixture proceeded more rapidly, up to ½-milk; still

weaker dilutions were again evacuated somewhat more slowly. Boiling the milk had no constant effect. The individual variations were great. Theile (159) stated that acidifying the milk by means of an acetate buffer did not retard the evacuation; alcalizing (phosphate buffer) clearly accelerated it. Krüger (95) examined infants who had been fed the mixture in question for a long period. Approximately, the evacuation time for breast milk was 2¼ to 3½ hours, whole cow's milk, 4 hours; one-half-milk, 3 to 3½ hours; buttermilk and skimmed milk 2 to 4 hours. Demuth (37, 38) found that the »normal» amount of milk was soonest evacuated; the evacuation of both very great and very small meals was retarded. In young infants, casein seemed to have a stronger retarding effect than fat. Adding hydrochloric acid did not alter the evacuation time of a milk mixture. Bessau, Rosenbaum and Leichtentritt (10) investigated extensively the influence of different factors. Small amounts were always rapidly evacuated; constant differences were found only when the meal given was either normal or great for the size of the infant. Breast milk was evacuated sooner (average 2½ hours) than whole cow's milk (3¼ hours). A high fat content retarded evacuation; breast milk fat and butterfat had here about the same effectiveness. Carbohydrates in amounts of 5% of the mixture had no effect; nor had the whey salts. Both casein and whey albumin had a distinctly retarding effect. Previous curdling of the casein by means of rennet or acid had no certain effect. On the contrary, a peptic predigestion had a strong accelerating effect, as had also, to a lesser degree, a tryptic predigestion. Cow's milk diluted to equal the protein percentage of breast milk (i.e., ⅓-milk) was still evacuated somewhat slower than breast milk. Demuth (40) and Izumita (84) found generally longer total evacuation times and smaller differences between breast milk and cow's milk than other authors. Compared with breast milk, buttermilk was evacuated somewhat more rapidly, ½-milk about as rapidly as breast milk, ⅔- and whole milk slower, soured skimmed milk very slowly. — Poole and Cooley (120) found that evaporated milk left the stomach as rapidly as breast milk. Reynolds, Macy and Souders (125) found, in children of 7 to 11 years of age, the following average evacuation times: pasteurized milk, 227 minutes; evaporated, reconstituted milk 214 min.; base-exchanged milk, 193 minutes. The significance of these differences has been contested (see 165).

In all investigations quoted above the endpoint of the evacua-

tion time has been the disappearance of the last trace of food from the stomach; this has often been checked by means of gavage.

Freudenberg and Wittich (55), performing jejunal catheterisations, found that the evacuation of breast milk from the stomach starts later but proceeds more rapidly than that of cow's milk. Cow's milk dilutions advance more rapidly in the intestine than undiluted milk, boiled cow's milk more rapidly than raw milk. Lactic acid milk is evacuated less rapidly than ordinary cow's milk.

Vendel (166) criticizes the X-ray method. He has at regular intervals taken up the gastric contents by means of gavage, measured them and returned them to the stomach. He found the evacuation to be »rectilinear» at first, i.e., with the same infant and same food, the volume evacuated per unit of time is constant. When 70 to 90% of the food has left the stomach, the evacuation is retarded and the disappearance of the last remaining food takes relatively a very long time, thus making it difficult to determine the endpoint of evacuation. In his opinion, the »ideal evacuation time» extrapolated by means of the rectilinear part of the curve would better characterize the behaviour of the food in question in the stomach. Keller (88) using the same method found that the evacuation rate of the same food in different infants is proportional to the body surface. Von Pirquet assumed that the intestinal surface is proportional to the body surface. If this is true, in infants of different age a given surface area of the intestine would always receive the same quantity of chymus per unit of time. This quantity, varying with different kinds of food, might be used as a means of measuring the digestibility.

3. On Some Milk Modifications

In the following only such methods will be discussed as aim mainly to modifying the casein curd.

The older theories concerning the qualitative dangerousness of the different constituents of cow's milk (fat, casein, whey salts or whey protein) have step by step fallen into oblivion. According to the present opinion, »the essential difference between cow's milk and human milk, as far as the infant's digestion is concerned, is related to the size of the curd in the stomach, and possibly in lesser degree to the buffer value» (Jeans and Marriott, 86). When raw, untreated cow's milk is curdled by rennin, quite small, soft casein

flakes appear at first. They unite rapidly to form larger and larger masses. The curd thus formed, which also includes almost the entire fat of the milk, shrinks exuding whey. Thus a considerably hard, elastic body is formed which can be attacked by the digestive enzymes only from the surface. (Brennemann, 16). In an adult's stomach the curdling occurs very similarly to that *in vitro*. A slow drinking of the milk seems only to further the incidence of very great compact curds (14).

There are differences in the hardness of the curds from the milks of different cows; in some cases the curd is rather soft. Hill (73) published a method of the determination of the curd tension, i.e. the power in grammes necessary to pull or push a knife of a certain type through a curd mass, produced by a precisely defined method. In untreated milk, this varies between 15 and 200 grammes. If the curd tension is less than 30 grammes, the milk is classified as »soft curd milk». It has been proved that the natural »soft curd» milks are milks in which the percentages of solids, solids-not-fat, fat and ash are lower than usual. Casein seems to have most effect on the curd tension. No qualitative differences can be found (41). Hill originally suggested that cows producing soft curd milk should be selected to form special herds, which would produce milk for infant feeding; this has been done in the U.S.A. on a large scale. The curd tension has also been the main criterion in the developing of many milk modifications. Lately it has been claimed, however, that the correlation between this test and the digestibility of milk is rather poor (43) and efforts have been made towards developing a better method, based on the size of the curd particles (153).

The American Medical Association Council on Foods (27) presented in 1937 a comprehensive survey of literature on the nutritional significance of the curd tension (including artificial soft curd milks). The conclusion was that, while it has been proved that soft curd milks are well tolerated and assimilated, »the evidence is meager, however, that any soft curd milks are 'better digested' or more completely digested than ordinary boiled milk.»

Artificially, a more or less fine curdling may be produced by one of several methods:

Diluting. — The diluting of milk for infant feeding is an age-old custom. Towards the end of the last century, very dilute mixtures like $\frac{1}{3}$-and $\frac{1}{4}$-milk were in use; their protein content and buffer

values approximate to the corresponding values of breast milk. However, infants do not thrive on such weak feeds. The weakest milk mixture in use nowadays is the ½-milk. In practice, diluting appears seldom alone, the milk being usually treated in other ways also, e.g. by heating.

The Use of Protective Colloids. — The use of a decoct made from grain, flour or starch for diluting the milk is, too, an old popular custom. It causes the casein to curdle in a still somewhat finer form than when plain water is used. Mono- and disaccharids have no such effect in the concentrations which may be used in practice. It would appear that the use of a starch-containing liquid for dilution is more common in Europe (cf. e.g., 28, 53, 11, 99) than in the United States (e.g., 80, 116, 86). Those who recommend it usually stress that it is preferable to give a part of the carbohydrate in a form requiring several stages of hydrolysis. This will spread the adsorption of sugar over a longer period of time, and make its rate more uniform, which ought to be an advantage according to clinical experience. Others, again, claim that an addition of starch to the food of infants is wholly unnecessary during the first months of life although the infant tolerates small amounts of it very well. The boiling of milk, in their opinion, makes it possible to do without the protective colloid effect of starch.

Of other protective colloids which have been in use, the following may be mentioned: gelatin, 1 to 2% (168); agar, 1% (140); gum arabic (acacia) about 6% (152). The two first-mentioned milks have been used only for therapeutic purposes in digestive disturbances, not as normal food. The acacia addition is claimed to decrease the incidence of digestive disturbances and to improve growth, as well as the nitrogen and mineral retentions.

Heating. — Through experience it is known that a heating of milk prevents it from souring. When the bacteria became known, the milk was heated in order to destroy its germs, and this effect was first thought to be the only cause of the improved results found in infant feeding with boiled milk. Later it has been found, however, that heating also causes many other changes in milk, most of which are advantageous for the digestion.

The heat coagulates the albumins and globulins. A part of the carbon dioxide is evaporated, causing a part of the calcium and the phosphates to form insoluble tricalcium phosphate. The dicalcium citrate is transformed into poorly soluble tricalcium citrate. Thus

the buffer capacity decreases somewhat. The casein of heated milk is curdled by rennet in considerably softer and less coherent particles than that of raw milk. A milk which has been heated to more than 60° C is unsuitable for cheese fabrication (99). It is uncertain whether there is a change in the casein itself (127, 86) or whether this mode of curdling is caused by the above described changes in the minerals (99). Pasteurization has only a slight influence on either the curd tension (41) or the digestibility of milk in the sense applicable in the present paper (43).

Evaporated milk is standardized in the U.S.A. It is prepared from fresh milk, the fat percentage of which is regulated to 3.9. It is then vacuum evaporated at 55° C until about 60% of the water is withdrawn, then homogenized and canned. The cans are sealed hermetically and autoclaved at 115° C for 15 to 20 minutes. The product has to contain at least 7.9% fat and 25.9% total solids.

As a result of the heating, the casein forms a very fine and soft curd through rennet action (47, 116, 86, 99).

In the dried milk industry, two different methods are in use. In the Just-Hatmaker or roller method the milk is dried as a thin layer on the surface of rotating cylinders which are heated by steam at about 140° C. The milk is thus heated to about 100°C and chemical changes, similar to those which occur during boiling take part. The rennin curd is, accordingly, soft and flaky (99). In the spray method very thin jets of milk are injected into a hot chamber through which a current of hot air passes; the milk powder is deposited on the floor of the chamber in very fine flakes. The milk drops are here heated only to about 40° C and practically no chemical changes occur. Accordingly, the product is more readily soluble than roller-dried milk, wherefore the spray method is the more common one nowadays. Such a slight heating does not alter the character of the casein curd (99). It must be kept in mind, however, that both evaporated and dried milk are practically always also homogenized before the evaporating or drying, the effect of which will be treated below.

It may also be mentioned that boiling and to some extent already pasteurizing, destroy the trypsin inhibiting factor found by Wallen-Lawrence and Koch (167). These authorities do not, however, regard this as an important clinical factor, as compared with the curd alteration through heating.

Homogenizing aims at diminishing the size of the fat particles

of milk, thus reducing their tendencies towards rising and coalescing. The flavor of milk so treated is richer than that of untreated milk and it cannot be skimmed; the fat remains evenly distributed for a long time, which is an advantage especially in mass feedings as in institutions, schools, restaurants etc. It has been found that homogenising also tends to make the casein (rennet) curd softer and less coherent. There may be at least two reasons for this (172). First the increased number of fat particles increases the amount of »weak spots» in the coagulum. Secondly, when the collective surface of the fat globules augments, it increases the amount of casein adsorbed into their membranes; while in untreated milk this fraction of casein amounts to only 2 to 3%, it increases through homogenization to 25 to 30% (99). It is assumed that the behavior of this part of the casein differs during curdling from that of the main part. Still other explanations have been advanced (41). The American evaporated milk is always, and dried milk almost always homogenized during the processing. — In Finland, homogenized milk has not won the favor of the housewife and it is therefore not much used.

Addition of Chemicals. — In order to retard or prevent the curdling, the following substances have been much in use, especially in the Anglo-Saxon countries during the first decades of this century: calcium hydroxide (as lime water, 20 to 25% of the amount of milk); magnesium hydroxide; and sodium citrate (2%). The theoretical background of these methods is partly obscure, and they are nowadays little used (see 63, 4, 86, 99).

The base-exchange method which has been used to some extent in the U.S.A aims at reducing the amount of soluble calcium. The milk, slightly acidified with citric acid, is allowed to trickle through a bed of zeolite (a synthetic silicate). The calcium, phosphorus, chloride and potassium contents decrease while sodium and magnesium increase (125). The calcium retention in feeding experiments remains normal (70, 71). The curd tension of this milk at room temperature is very low, but increases considerably through boiling or even heating to 38° C, which makes the advantages of the method questionable. Doan and Flora (42) did not find any improved digestibility *in vitro*. Sodium metaphosphate has been added to the milk in order to bind the calcium to a complex ion (145). In rat feeding experiments the calcium adsorption was improved. In digestibility experiments *in vitro* this milk does not appear to be very advantageous (43).

The »Humana-Milch» of Lemke (97) is a preparation from cow's milk in which the removal of more than one-half of the calcium (through precipitation with sodium carbonate and calcium oxide) and about two thirds of the casein are claimed to modify the curd so that it is quite similar in texture and curd particle size to that of breast milk.

Pre-curdling of the casein through an addition of an acid or enzyme is the principle most commonly used in our days.

a) *Milks Soured by the Action of Microbes.* — Many peoples have used from time immemorial soured milk as a nutriment. Depending on the temperature of the fermentation, the treatment of the milk, climate, etc. the microbe flora used varies in different countries; the products are also, naturally, different. Sometimes the ferment consists of only one kind of microbe, sometimes of a symbiosis of several species. Of these »natural» sour milks the following may be mentioned: the *piimä, filbunke* or *taette* of Northern Europe (*Streptococcus lactis* or *Str. cremoris* (Orla-Jensen); the Caucasian *kefir* (three species of lactic acid streptococci, *Lactobacillus caucasicus* and a yeast (*Torula*); the *leben* of Egypt and Libanon (two bacilli, a coccus and two yeasts); the Sardinian *gioddu* (a bacillus and a saccharomyces); and the Bulgarian *yoghurt* (*Lactobacillus bulgaricus* and *Str. thermophilus*).

Related to these are the acidophilus milk (*Lactobacillus acidophilus*), produced industrially especially in the U.S.A. but scarcely used as sole food, and the bifidus milk (*L. bifidus*) recently developed in Germany (107). Buttermilk is a by-product obtained when milk, previously soured by *Streptococcus lactis* or *Str. cremoris* is churned in order to prepare butter.

In all these milks, the main phenomenon is the bacterial production of lactic acid from lactose. Often also some amounts of other acids, e.g. acetic and succinic acids are formed (see, e.g., 127). The yeasts included in the symbioses ferment a part of the sugar to alcohol (e.g., in the *kefir*). — When the amount of acid (counted as lactic acid) rises to 0.5 to 0.7%, the isoelectric point of casein (about *p*H 4.6) is reached and the casein coagulates in fine flakes. The lactic acid streptococci do not produce much more acid than this, while the *Lactobacillus* species may augment the acid content to 2%, given sufficient time.

We know that Metschnikoff's original idea was to change the intestinal flora by means of yoghurt in such a way that the fer-

mentation bacteria would dominate and so decrease the amount of putrefaction bacteria. A lasting effect cannot, however, be obtained; even bacteria found normally in the intestine (e.g., *L. acidophilus* or *L. bifidus*) decrease rapidly in some days or weeks after the patient has ceased to ingest a milk fermented with these bacteria. Still less do other than intestinal bacteria settle permanently in the colon. The better effect of such fermented milks, as compared with untreated milk, probably depends on the better digestibility brought about by the acid flocculation of casein. Further, the fat tolerance of infants, especially of convalescents from enteritis, is greater with acid milk than when »sweet» milk mixtures are used, which makes it possible to administer more calories (e.g., 28). Klotz (92) found small amounts of lactic acid (1 to 2 grams a day) to have a »tonizing» effect.

In those countries where one of the sour milks mentioned above is commonly used, it is probably often given to quite young infants. Presumably the microbe strain and quality of such a product remain relatively constant through a taste and odor control; we know that an experienced dairyman notices an alteration of a buttermilk culture by tasting and smelling it long before a change could be demonstrated by means of any bacteriological or chemical method. — In other circumstances, however, the microbe culture should be obtained from a reliable laboratory, and be renewed often, which then makes the use of such milks inconvenient.

A soup of buttermilk and flour has old traditions in infant feeding in Holland and Flanders. It was brought into the realm of scientific pediatrics by Teixeira de Mattos (158) and Salge (133). The low fat content (usually about 1%) of ordinary buttermilk is a drawback, but in many countries a special buttermilk, richer in fat, is prepared for infant feeding.

The North European sour milk has been used with success for the feeding of infants starting at an age of three months, (121; the writer's own observations in Finland, Province of Lapland); but no systematic feeding experiments with it have been published.

The kefir has during a certain period been used especially in the treatment of acute intestinal disturbances and for convalescents; it has also been recommended as a normal diet (163, 44) but nowadays it is scarcely used to any extent outside its homeland (99).

The gioddu has been used for infant feeding by some Italian pediatricians (20, 151). In Bulgaria yoghurt is the absolutely pre-

dominant artificial food for infants; also the welfare centers and hospitals are using it (59, 132). It has also been used elsewhere, with varying results (91, 147, 96).

It is difficult to maintain the purity of a microbe culture of this kind, especially when used in private homes; also it was found that the favourable effect of the natural sour milks was not bound to the presence of living bacteria. Thus it seemed natural to experiment with an acidification of milk without using bacteria, by adding a quantity of a suitable acid to the milk.

b) *Milks Soured by Addition of Acids.* — Marriott and Davidson (105, 106) recommended a lactic acid whole milk as a standard food for infants. They used a concentrated lactic acid (85%) adding it to boiled milk which had subsequently been cooled to the temperature of ice water. During the drop by drop addition of acid the milk was stirred vigorously until the first signs of curdling appeared; thus the amount of acid to be added varied somewhat depending on the buffer capacity of the milk.

Scheer (139) had already in 1922 proposed the use of a hydrochloric acid milk (260 ml of n/10 HCl to 740 ml of milk); this was intended for the treatment of spasmophilia. Faber (49) experimented with it in the treatment of diarrhea but proposed himself that an oxydizable organic acid might be more suitable. Greene (62) proved that the use of hydrochloric acid milk causes a considerable irritation of the kidneys.

Marriott and Davidson in 1923 were still influenced by the earlier theories on the genesis of diarrhea and presumed that, e.g., acetic acid and citric acid would irritate the intestine and thus produce diarrhea. This presumption was proved false when Dunham (46) developed the acetic acid milk and Weissenberg (169, 170) the citric acid milk, both reporting good results. The latter of these has won much favor in many countries though some use it in a diluted form (then generally as a $^2/_3$-milk). Others claim that acid whole milks are suitable only for prematures, convalescents and others who are in need of a food especially rich in calories and protein, while it is too concentrated for general use. (For literature on lactic and citric acid milks see further, e.g., 110, 60, 148, 128, 124, 138, 89, 141, 102, 103, 50, 25, 108, 122, 99).

Good results have also been reported by authors using other kinds of acid additions like lemon juice (68, 6, 104); dried apple powder (123); here the acidifying effect is slight but evidently the

protective colloid effect of the pectins plays a great rôle; borsch (93); adipinic acid (13), etc.

The acid milks are generally held to have the following three advantages:

1. The casein, under the influence of the acid, forms a very fine curd which remains as such also under the influence of rennin. Lactic acid must be added very slowly and to a well cooled milk in order to obtain a fine curd (105, 106). With citric acid, somewhat less care is needed in these respects (60). In natural, fermented sour milks the increase of acidity always occurs sufficiently slowly.

2. The acid takes care of a part of the buffer capacity of the milk; thus the stomach does not need to excrete »unphysiological» amounts of hydrochloric acid, as when »sweet» cow's milk mixtures are used. Marriott and Davidson (105) calculated that their lactic acid milk would need the same quantity of HCl as breast milk would if both were to reach *p*H 3.8, while whole cow's milk would need three times as much. Calculating from the *p*H values and buffering curves of Demuth (40), buttermilk would *in vivo* cause only ¼ to ½ of the acid secretion called forth by breast milk or 1/12 to 1/6 of that caused by whole cow's milk. He does not, however, take into account the effect of lipolysis on the acidity of the stomach. Taking this factor into consideration, Brock (17) concludes that acid whole milk needs about one-third of the amount of hydrochloric acid required by whole milk or about one half of that required by $^2/_3$-milk. Evidently this is advantageous especially during and after infections, when the acid secreting capacity of the stomach is impaired. Brock proposes that in healthy subjects this saving of acid might be a disadvantage, if, that is, the secretion of pepsin were to decrease in proportion. Lust (99) thinks that it would be nearer to physiologicai conditions to let the stomach perform the last part of the acidification. Espe and Dye (48) found, however, that a small addition of acetic acid to the milk before a rennet curdling tended to make the curd harder and more compact. Also, in the *in vitro* experiments of Doan and Dizikes (43) lactic acid milk of *p*H 5.4 to 5.7 formed rather coarse curd particles giving a relatively unfavorable digestion diagram.

Brennemann (15, 16) has heavily stressed his opinion that the clinical importance of the fineness of the curd is by far greater than that of the diminished buffer capacity. Among his arguments are, e.g.: Moll (112) and others have equally good results with neutra-

lised and sour buttermilk; further, in all clinically well-established milk modification procedures, as, e.g., the use of evaporated or dried milk; boiling; diluting; the use of protective colloids; addition of acid or alkali (in the latter case, the buffer capacity rises above the level or ordinary milk!); addition of sodium citrate; etc. — in all these methods there is one and only one feature common to all of them: they change the milk so as to produce a finer casein curd than ordinary milk.

3. The acid has an inhibiting effect on the growth of many species of bacteria. In some earlier papers, even the evidently exaggerated term »antiseptic» is found. The reaction of Marriott's lactic acid milk and Weissenberg's citric acid milk (*p*H 4.1 to 4.5) almost totally inhibits the growth of *Escherichia coli*, the hemolytic streptococci, the enterococci and the Salmonellas; the growth of sporiferous bacilli is impaired; but the lactic acid streptococci and the Aerobacter group thrive even better than in the original milk (114, 7, 61).

In consequence, the innocuousness of acid milks, as to bacteria, cannot be blindly relied upon. However, an acid milk prepared from milk brought to the boil or boiled milk will keep at room temperature better than a non-acid milk. This is a great advantage in the tropics and in general in all circumstances where there is no sufficiently cool storage place available for the milk.

In the natural, fermented acid milks the mutual competition of the bacteria inhibits the growth of pathogenic microbes already long before a significant degree of acidity is reached. They are, however, generally not destroyed; therefore a milk used to these products ought to be pasteurized or brought to the boil unless it is absolutely fresh and pure.

Some authorities mention still one advantage of the fermented milks, viz. some degree of proteolysis caused by the bacteria. The amount thus predigested is, however, a very small part of the total protein (2.5%: 90).

The curdling of casein by Means of Salts. — The addition of a salt, even a neutral one, to the milk decreases the electrical charge and the hydration, thus producing a flocculation. Moll (113) used 5 g of calcium lactate to a liter of milk (»Calcia-milk»). Schaps (137) used acid calcium lactate for the milk mixtures of dyspepsia cases.

Treatment of milk with enzymes. — Pepsin, trypsin and papain have been used, but not to any great extent. v. Dungern (45) pro-

posed the use of rennet in order to render the milk more digestible: by performing the curdling at the optimal reaction of rennin (*p*H 6.6) and not at the reaction of the stomach (*p*H about 5.5) the casein is curdled in a relatively fine form. In experiments *in vitro* Spur and Wolman (154) showed that this treatment somewhat improved the peptic digestibility of the casein curd.

4. On Digestion Experiments in vitro and in vivo

Brennemann (14) performed a great number of experiments on an adult subject who could with ease voluntarily regurgitate his gastric contents. Raw cow's milk rapidly ingested (5 minutes) formed curds of a diameter of several centimeters; when ingested slowly (45 minutes) probably one single curd was formed, too great to pass through the esophagus. Five hours after the drinking of raw milk there were still curds of 2,5 cm of diameter in the stomach. The curds of boiled milk were the size of hazelnuts and peas. The curds of pasteurized milk were between the two sizes mentioned, nearer the raw milk. Raw milk diluted with water 1: 1 curdled in fine grains or threads. If the milk was boiled before the diluting the curd was much finer still; the use of barley water (in diluting raw milk) had somewhat less effect. Sodium citrate and sodium bicarbonate solutions as well as lime water also made the curd very soft and friable.

Orla-Jensen and Spur (119) investigated *in vitro* the effect of the addition of different amounts of lactic acid to sterilized milk. Determining the proportion of soluble nitrogen to total nitrogen they found increasing digestibility with increasing acidity. The differences were small, but it must be remembered that the heating during sterilization already causes a great improvement in digestibility as compared with raw milk.

Hess, Koch and Sennewald (69) performed *in vitro* experiments using a pepsin solution and 30 ml. of n/10 HCl to 100 ml of milk; the digestion time was 4 to 6 hours in a rocking apparatus at 40—42° C. The increase of soluble nitrogen was determined. Pasteurized milk behaved like raw milk. Boiled milk contained about $\frac{1}{3}$ less of soluble nitrogen at zero time than did raw milk (coagulation of albumin through heat) but the result was better than with raw milk. The addition of acid (lactic, hydrochloric and citric acids, and fruit juices) also decreased the original amount of soluble nitrogen,

roughly in proportion to the acidity of the milk mixture, but improved the digestion of the protein. A fermented acid milk (*p*H 4.15) was remarkably well digested, better than a lactic acid milk (ad modum Marriott) of the same *p*H. — The same milks were also fed to pups which were made to vomit (by means of an apomorphine injection), ½ hour after the meal. The curd of raw milk formed one single hard mass; the curds of boiled, hydrochloric acid and fruit juice milks were of half-pea size, while the curds of lactic acid and fermented milks equaled the size of coarse sand grains. If the sample was not taken till after two hours p.c. the curds were greater; evidently some cohesion had taken place, especially in raw milk. The lactic acid and fermented milk curds were still the finest ones.

Espe and Dye (48) investigated the effect of the curd tension of several skimmed milk mixtures on the digestibility. They used dogs, estimating the duration and quality of secretion from a Pavlow pouch. The duration of the secretion i.e. gastric digestion became shorter with decreasing curd tension.

Ogilvie and Peden (117) fed raw and boiled milk to infants between 3 and 23 months of age. They determined the amounts of acid and pepsin as well as the amount of nitrogen in the filtrates after trichloracetic acid precipitation, taking half-hourly samples. They did not find any certain differences in the digestion of these two milks.

Fetter and Schlutz (51) mixed equal amounts of the milk sample and a synthetic gastric juice, containing pepsin, 0.5% hydrochloric acid and in part of the cases, rennet. The acidity was regulated by adding amounts of NaOH- or $NaHCO_3$-solutions. The mixtures were shaken at 37° C for 8 hours and samples taken at two-hourly intervals. Generally, ⅓ to ½ of the total digestion took place during the first two hours. At a low *p*H (1.8 to 3.0) the addition of rennet did not improve the digestion; around *p*H 4.0 to 5.0, little digestion took place if no rennet was added. With most milks, the effectivity of the rennet-containing mixtures was better at *p*H 4.5 and about *p*H 2.0 than at *p*H 3. As the proteolysis thus seemed to have two *p*H-optima, it is probable that the rennet preparation contained cathepsin. — The digestion of evaporated, dried and lactic acid milks was somewhat better than that of untreated milk. The same authorities performed *in vivo* experiments (52) on children between 7 and 14 years of age. They took samples of the gastric contents by means of a stomach tube at certain times after the

ingestion of the milk and determined the percentage of soluble nitrogen. The highest value found with each milk was held to represent »the height of digestion» which thus would be attained the sooner, the more digestible the milk was. The order of digestibility found, from better to poorer, was as follows: buttermilk; rennet milk; lactic acid and evaporated milks; dried milk; untreated milk.

Doan and Flora (42), working *in vitro*, used an artificial gastric juice containing HCl, rennet and pepsin; HCl was further added half-hourly during the digestion, thus changing the acidity of the mixture in 2½ hours from about *p*H 6 to about *p*H 3.5. An appropriate number of identical samples were shaken in bottles at 37° C. At the beginning of the fourth hour, the contents of the flasks were adjusted to a *p*H of approximately 7 using normal sodium hydroxide solution; then, trypsin solution was added. At the end of the fourth hour the *p*H was adjusted to about 8.1 and the digestion was carried on for a further two hours. At the beginning of the experiments, as well as after every full hour, a flask was removed for nitrogen determination of the fraction of the material which passed through a 12-mesh screen. (»The 12-mesh was judged to represent the size of protein particle liable to pass the pyloric sphincter».) In many cases, the three-hour sample was also analyzed for the nitrogen fraction not precipitable with 2.5% trichloracetic acid and the four- and six-hour samples for nitrogen not precipitable with tungstic acid. They found that the digestibility of raw milk increased with decreasing curd tension; boiling improved the digestibility quite markedly; homogenisation seemed to impair it somewhat. An addition of acid considerably improved the digestibility, even when the amount was not great (e.g., in citric acid milk of *p*H 5.64). Evaporated milk was as easily digested as buttermilk. The effect of the base exchange treatment on the digestibility was slight in spite of its markedly lowering the curd tension. Trypsin treatment improved somewhat the digestibility. — The milks under examination were also fed to young rats, specimens of which were killed after 1½ hours and 3½ hours from the feeding. The amount and appearance of the curd and its localisation in the digestive canal was noted. The results agreed well with the findings from *in vitro* experiments, the only difference being that here homogenization seemed to have a beneficial effect. Doan and Dizikes (43) used the same artificial gastric juice, but performed the digestion

in thin-walled rubber bags which were rocked in a water bath. They divided the casein into five different fractions by means of four screens and a filter paper, and determined the nitrogen content of these as well as of the filtrate at zero time and after 1, 2 and 3 hours of peptic digestion. The results were given as per cents of the total nitrogen of the sample, and the digestibility was judged by the decrease of the curd particle size. The digestibility of breast milk was by far the best. Even before the digestion practically all of the nitrogen passed a 40-mesh screen. Of different kinds of cow's milk (all undiluted), lactic acid milk and buttermilk (*p*H 4.0—4.5) were the most easily digested ones, closely followed by superheated soft curd milk and evaporated milk. Clearly less digestible were lactic acid milk of *p*H 5.4—5.7, boiled milk and homogenized milk, with only small differences within this group. After these came the metaphosphate and trypsin milks and the last, least digestible group was formed by raw cow's milk, pasteurised milk and locust bean gum (0,1 %) milk as well as raw goat's milk.

Turner (165) determined the relative amount of filtrate nitrogen at *p*H 4.7, using both peptic and tryptic digestion. Samples were taken after 5 and 30 minutes, respectively, of peptic digestion. After this, sodium hydroxide and duodenal enzymes were added. The *p*H was adjusted to 7.5 and further samples were taken after 15, 70, 90, 120, 150 and 180 minutes of tryptic digestion. In the group of milks not heated above 65° C, pasteurising, homogenising, zeolite treatment, skimming, and skimming-and-roller-drying did not seem to have any effect on the digestibility. Trypsin treatment improved, addition of barium sulphate (as for X-ray investigations) impaired the digestibility. In the group of milks heated to at least 87.5° C, the percentage of soluble nitrogen before the digestion was low, as could be expected (heat coagulation of lactalbumin). The digestibility was, however, improved as compared with the low-heated milks. Pasteurising, skimming, homogenization, drying and zeolite treatment did not seem to have any noticeable effects in themselves. The writer suggests that the good clinical results with homogenized and zeolite milks might depend upon the fact that no big curds are formed, which might mechanically irritate the infant's stomach.

Of other milks, goat's milk was less digestible than cow's milk whereas a sample of mare's milk proved highly digestible and a sample of breast milk even more so.

Wolman (173) performed some experiments on children between 3 and 14 years of age. He found a good correlation between the amounts of hydrochloric acid and pepsin; in the »pepsin activity curve» of the gastric juice there was deviation upward about *p*H 4.7—5.2 which would seem to indicate the presence of cathepsin. — Samples were taken through a stomach tube at 10-minute intervals. Homogenized milk coagulated more rapidly than untreated milk; this did not influence the gastric evacuation time. — Some experiments performed on three healthy infants between 6 and 11 months of age gave very variable results which allowed no conclusions.

Ilgner and Thurau (83) performed peptic and tryptic digestion experiments *in vitro* with untreated and homogenised milks. The latter was definitely more advantageous, especially when the digestion time was relatively short.

The experimental investigations on the digestibility of different kinds of modified milks are not very numerous. The results obtained are generally in good agreement with clinical experiments. It would seem probable that even experiments performed *in vitro*, if evaluated critically enough, would be of significance in the judging of the relative values of different methods of milk modification.

OWN INVESTIGATIONS

Method

The method used in the present work is almost identical with that of Doan and Dizikes (43).

The digestion takes place in thin-walled rubber bags, immersed into a water bath of 37° C. They are suspended from a horizontal bar by means of rimmed glass tubes about 2 cm in diameter and 7 cm in length. An electric motor rocks the bar longitudinally to and fro, the rate being 25 to 30 double movements per minute and the amplitude about 13 cm. Thus the contents of the bags are well mixed, but there is no forcible pressing or rubbing of the curd particles against each other. Doan and Dizikes imitated peristalsis by means of two opening and closing metal leaves which squeezed the tubes from the sides. As the minimum space between the leaves was ½ inch, it would seem that this unyielding pressure might purely mechanically break down big curd particles. All who have studied the infants stomach roentgenologically agree upon the peristalsis being very weak especially during the first months of age. Thus the writer's method would seem to imitate nature more closely.

Four bags were used for every milk sample to be examined. When they were in place, 7.5 ml of the artificial digestion mixture of Doan and Flora(42) were added to each bag (5.0 ml of 0.3% pepsin solution (U.S.P. 1: 3000, Difco), 2.0 ml of a 5% solution of Hansen's rennet extract and 0.5 ml of normal hydrochloric acid). Five minutes were allowed for tempering the digestion mixture. Then, 50 ml of milk were placed into each bag by means of a 50 ml pipette, the tip of which had been removed so that it emptied in about 4 seconds. The bags were allowed to stand 15 minutes for coagulation, after which a further 10.0 ml of the pepsin solution were added to each bag. Immediately after this the first bag was removed to represent the zero time of digestion, and the rocking apparatus was set in motion. After each half hour of digestion, the *p*H of the remaining bag contents was lowered by the addition of 0.75 ml (or, in a part of the experiments, 0.5 ml) of normal hydrochloric acid. The second bag was removed after one, the third after two and the fourth after three hours of digestion, respectively.

The contents of each removed bag were carefully emptied into a 250 ml Erlenmeyer flask, containing 25 ml of 35% formaldehyde and about 75 ml of water. The bag was carefully washed out with distilled water and the washings added to the bottle, the contents of which were made up to approximately 250 ml. The curds were then left to harden for at least 20 hours.

After this, the contents of each flask were poured through a series of screens = 4, 10, 20 and 40 mesh (the mesh number signifying the reciprocal of the side of a mesh hole; thus, e.g., the holes of a 4-mesh screen are ¼ × ¼ inches). By dripping distilled water from a height of about 10 cm, all particles capable of passing through the 4-mesh screen were made to go through. This screen was then removed and the same procedure repeated with the 10-mesh screen and so on. The mixture which had passed through all screens was filtered and the remainder on the filter washed. The amounts of particles retained by each of the screens and the filter paper as well as the filtrate were analyzed for nitrogen. At first, a modification (111) of the direct Nesslerization method of Koch and McMeekin was used. During the hot season, however, this method proved too sensitive to disturbing factors, wherefore the rest of the analyses was performed using the micro-Kjeldahl method, distilling the ammonia into a boric acid solution and titrating with 1/70-normal sulfuric acid, using bromcresyl purple as an indicator. In all about 2200 nitrogen determinations were performed.

The curd of the first (zero hour) samples was usually clearly softer and more friable than the curd of the digested samples, and the shape of the particles was more irregular, often branched or thread-like. Evidently the thoroughness of the washing was able to influence these results much; drops falling from a high position could no doubt have by and by ground curd particles to a smaller size. The writer has striven to perform the screening and washing as uniformly as possible and believes that this error does not influence the results in a decisive way. — In the 1, 2 and 3 hour samples this factor was no longer present. As mentioned in the literature review, in reality the evacuation into the intestine already begins soon after or even during the ingestion of the meal. Thus the first portion of food may enter the duodenum without having had time to curdle, and in any case a considerable part enters the intestine after a very brief peptic digestion. It would seem probable, however, that the fineness of the casein curd would further both the peptic and the tryptic digestions in about the same way. Thus, the 3-hour sample, in particular, will give an idea of the digestibility of the milk modification in question, having regard also to the entire digestive canal.

During the course of several of the experiments, a rough *p*H determination was performed by means of indicator paper, when removing the bag. The results were as follows:

	Hours			
	0	1	2	3
Cow's milk, raw and boiled	5.9	5.3	4.5	3.6
Dried and evaporated milks	5.5	4.9	4.4	3.7
Sour milks	4.5	4.2	3.8	3.3
2/3-milk	5.4	5.0	4.1	3.3
½-milk	5.4	4.8	3.7	3.2
Breast milk	5.7	4.8	3.9	3.0
Mare's milk	6.3	5.1	4.0	3.0

As here the *p*H of the 3-hour samples of, e.g., breast milk, mare's milk and ½-milk was considerably lower than the values found in the stomachs of infants being fed these milks, a part of the experiments were renewed adding half-hourly only 0.5 ml of hydrochloric acid instead of 0.75 ml. In these experiments the (very approximate) *p*H values were.

	Hours			
	0	1	2	3
Citric acid milk	4.8	4.5	4.2	3.8
½-milk (from dried milk)	5.4	5.1	4.6	3.8
Breast milk	5.6	4.9	4.2	3.6
Mare's milk	6.4	5.6	4.9	4.0

The results are given as per cents of the total nitrogen of the sample. From the percentages found in different experiments with the same milks, arithmetic means have been calculated. A part of the results obtained with raw cow's milk, breast milk, mare's milk and citric acid milk has already been used in another paper (87).

The Results

Breast Milk

Breast milk is the nutriment which Nature has intended for the suckling. It is most probable that natural selection has acted to adapt the properties of breast milk and the infant's digestion more and more to each other. Thus, breast milk is the standard by which other milks and milk mixtures, designed for infant feeding, ought to be compared. If the conditions of an experiment *in vitro* approximately correspond to the physiological conditions, it may be assumed that a milk or milk mixture is the more suitable and more easily digestible the more it behaves like breast milk in the experiment.

In hospitals and maternity homes it is often necessary to heat the breast milk in order to destroy the pathogenic germs before the feeding. Some authorities claim that raw breast milk gives distinctly better results in infant feeding than the same milk boiled (see, e.g. Catel and Wallituch (22), feeding experiments on prematures; Bernheim-Karrer, (9): five pairs of »identical» twins where the difference between birth weights had been but small; Catel (23): four pairs of twins).

One of the effects of heating is a coagulation of a part of the

milk albumin. As the greatest part of the breast milk protein consists of albumin, the coagulation could have some effect on the digestibility.

In cases where a mother privately donates or sells breast milk to another's infant, the destroying of germs usually is performed by bringing the milk to the boil.

The following kinds of breast milk were studied: a) milk heated to 63° C for 20 minutes, this being the current method used at the Children's Hospital and at the Breast Milk Bank of the Mannerheim League for Child Welfare, Helsinki, b) and c) raw breast milk and the same milk brought to the boil and rapidly cooled.

Results: Table 1 and Fig. 1.

TABLE 1

BREAST MILK; THE EFFECT OF HEATING

Type of milk	Digestion hours	Fractions					
		4-mesh	10-mesh	20-mesh	40-mesh	Filter paper	Filtrate
Breast milk	0	0	0	0	0	56.0	44.0
heated to 63°C	1	0	0	0	0	37.2	62.8
for 20 min.	2	0	0	0	0	18.6	81.4
(4 experiments)	3	0	0	0	0	11.2	88.8
Breast milk	0	0	0	0	0.3	50.4	49.3
raw	1	0	0	0	0.1	30.8	69.1
(7 experiments)	2	0	0	0	0	9.8	90.2
	3	0	0	0	0	8.8	91.2
Breast milk	0	0	0	0	0	63.5	36.5
brough to the	1	0	0	0	0	52.2	47.8
boil (7 experi-	2	0	0	0	0	23.3	76.7
ments)	3	0	0	0	0	13.3	86.7

The casein of breast milk forms a very fine curd; practically all of it even passes through the finest sieve used, and by zero time 40 to 50% of the protein is filterable. The digestion of raw breast milk reaches its maximum after two hours. After this period of time, the heated breast milks attain almost the same figures. Heating causes a relatively small impairment of the digestibility, bringing to boil having a greater effect than the holding pasteurization.

It is certain that the coagulation of the albumin is not by far the most important of the changes in the breast milk caused by heating. For instance heating destroys the breast milk lipase

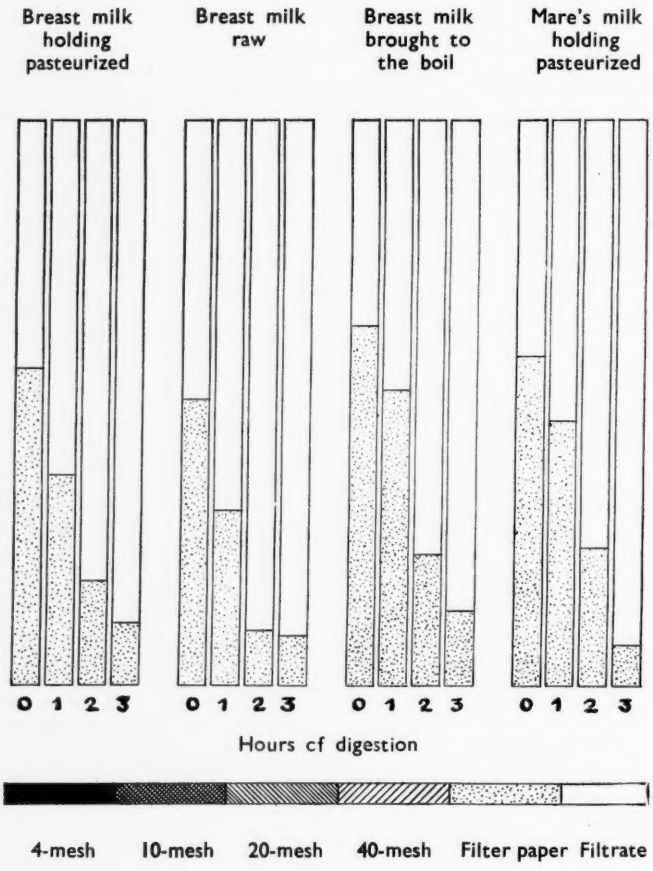

Fig. 1

which according to Freudenberg (54) plays a great rôle in the infant's digestion. Also it destroys the »eutrophising factor» described by Levesque and Bastin (98).

Mare's Milk

The milk of the ass has old traditions in the feeding of infants. Of all the milks of domestic animals it is chemically the most similar to breast milk. As late as in 1923 Ribadeau-Dumas (126) recommends it for children »whose digestive organs are too sensitive to tolerate even breast milk». As mare's milk is very similar to asses' milk and it is easier to obtain, Freudenberg (57) has tried it for infant feeding, with good results. It has also been in use at the

Children's Hospital of Helsinki (87). Because of the chemical similarity (a relatively high albumin and low casein content), it can be expected to behave similarly to breast milk. The milk was heated to 63° C for 20 minutes.

Results: Table 2 and Fig. 1.

TABLE 2

MARE'S MILK (8 EXPERIMENTS)

Digestion hours	Fractions					
	4-mesh	10-mesh	20-mesh	40-mesh	Filter paper	Filtrate
0	0	0	0	0	58.2	41.8
1	0	0	0	0	46.9	53.1
2	0	0	0	0	24.4	75.6
3	0	0	0	0	7.4	93.6

Mare's milk gives a digestion diagram similar to that of breast milk brought to the boil. This agrees well with the results of our feeding experiments.

Table 3

COW'S MILK, RAW AND HEATED

Type of milk	Digestion hours	Fractions					
		4-mesh	10-mesh	20-mesh	40-mesh	Filter paper	Filtrate
Raw milk (7 experiments)	0	73.3	0.8	0.3	0.2	2.2	23.2
	1	64.4	1.6	0.7	0.4	6.0	26.9
	2	57.7	2.0	0.8	0.5	5.8	33.2
	3	51.2	1.6	0.6	0.6	4.9	41.1
Milk brought to the boil (4 experiments)	0	40.3	10.1	12.0	14.0	11.2	12.4
	1	22.9	15.4	11.6	11.3	11.2	27.6
	2	37.6	8.4	5.9	5.8	10.1	32.2
	3	31.7	7.7	5.7	3.4	10.6	40.9
Milk boiled for 5 min. (4 experiments)	0	4.9	8.1	10.5	40.4	20.0	16.1
	1	15.5	15.7	17.1	14.0	11.0	26.8
	2	15.2	17.8	11.4	8.3	13.0	34.3
	3	13.5	14.4	6.6	4.9	16.9	43.7
Milk boiled for 10 min. (4 experiments)	0	0.4	11.3	14.7	36.8	22.0	15.4
	1	2.3	15.5	17.7	20.0	15.0	29.5
	2	8.8	15.9	10.4	13.5	14.7	36.7
	3	5.0	15.9	8.3	6.8	16.8	47.3

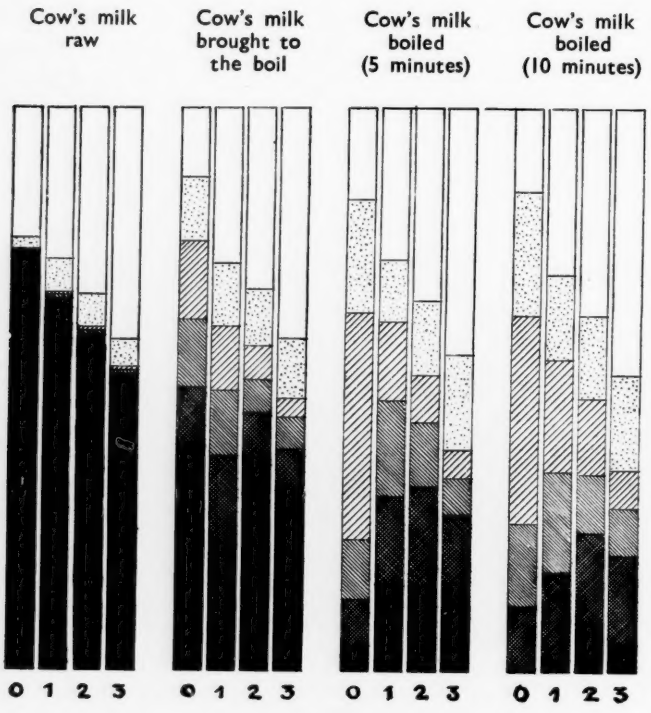
Cow's milk raw
Cow's milk brought to the boil
Cow's milk boiled (5 minutes)
Cow's milk boiled (10 minutes)
0 1 2 3
0 1 2 3
0 1 2 3
0 1 2 3
Hours of digestion

Fig. 2

Cow's Milk; the Effect of Heating

In three experiments with raw milk, ordinary commercial milk containing 3.5% fat was used. In the other experiments the milk was so-called controlled milk, i.e. coming from especially clean and well supervised dairy farms; the fat content was 3.8% or more. The heated milk samples were cooled rapidly by means of running tap water.

Results: Table 3 and Fig. 2.

In three cases, the *same* milk was investigated raw, brought to the boil, boiled for 5 mins. and boiled for 10 minutes, respectively. The mean values from these experiments only are presented in table 4.

As can be seen, the results are not essentially different from those in table 3.

Almost all of the casein of raw cow's milk forms one single curd

TABLE 4

Type of milk	Digestion hours	Fractions					
		4-mesh	10-mesh	20-mesh	40-mesh	Filter paper	Filtrate
Raw	0	75.6	0.9	0.4	0.3	1.9	20.9
milk	1	62.1	2.4	0.9	0.4	6.7	27.6
(3 experi-	2	57.0	2.3	0.8	0.5	7.4	32.0
ments)	3	54.0	2.0	0.6	0.4	5.0	38.0
Milk brought	0	27.3	11.4	15.2	18.1	13.9	14.1
to the boil	1	17.1	15.1	13.8	14.3	13.9	25.8
(3 experi-	2	29.7	10.9	7.6	7.4	11.6	32.8
ments)	3	25.3	9.8	7.1	4.0	12.6	41.2
Milk boiled	0	1.2	6.7	10.9	43.8	21.3	16.1
for 5 min.	1	1.7	18.5	21.4	17.4	13.5	27.4
(3 experi-	2	8.5	17.5	13.7	9.9	14.7	35.7
ments)	3	10.0	13.4	7.3	5.5	18.5	45.3
Milk boiled	0	0.3	7.2	10.1	39.7	26.2	16.5
for 10 min.	1	3.0	14.6	19.5	21.4	14.7	26.8
(3 experi-	2	5.5	14.5	11.9	15.8	16.9	35.4
ments)	3	3.3	15.1	9.8	7.7	17.9	46.1

which appears to be cast in the digestion bag. At zero time it is still comparatively soft, but then it becomes gradually more and more solid, contracting, exuding whey and being digested on the surface only. Thus the increase of filterable nitrogen is slight.

Allaria (3) claims that saliva might to some extent act as an protective colloid in the stomach. However, to judge from the experiments of Brennemann (14) and from the hard casein curds found in the stools of infants fed on raw cow's milk, this milk evidently forms rather large curds also in the stomach of infants.

A rapid heating of milk to the boiling point, followed by a rapid cooling, brings about a great change in the type of curdling. Especially at zero time the curd is much softer and more friable than with raw milk, but a considerable part of it is still retained even by the first screen. During the digestion the curd particles are markedly solidified, almost as in raw milk.

The results of boiling five and ten minutes, respectively, are practically equal: the curd is again much finer, as in the previous type of milk. Almost everything passes through the 4-mesh screen. In the zero time samples, the fraction retained by the 40-mesh screen is especially great, but after one hour's digestion, the pro-

portion of this fraction has decreased in favor of the larger particles. Evidently the heating has considerably lowered the tendency of the curd particles' to coalesce, but has not destroyed this tendency completely. Thus the coagulation period of 15 minutes is not sufficient for the completion of this process; it continues during the first hour of the digestion. — The same phenomenon appears in the experiments on dried milk.

In these milks a solidification of the curds during the digestion is also seen and in this respect there is no clear difference between them and the two previous kinds of milk.

In all these heated milks the percentage of filterable nitrogen in the zero hour sample is smaller than in raw milk. This is evidently due to a heat coagulation of lactalbumin. This loss in filterable nitrogen is, however, recovered during the first hour of digestion.

A scrutiny of the diagrams leads to the impression that in some of the heated milks the increase of filterable nitrogen takes place chiefly at the cost of relatively fine curd particles (the 40-mesh fraction), whereas especially the two coarsest fractions remain nearly untouched. This probably does not depend on the size of the curd particles only, but also on their relatively solid consistency which prevents the digestive mixture from penetrating to their inner parts. The number of the experiments does not, however, allow any certain conclusions.

Dried Milk

The dried milk used for the experiments was American, spray-dried, of two different brands. The reconstitution was performed according to the manufacturer's instructions.

Results: Table 5 and Fig. 3.

TABLE 5

DRIED MILK (6 EXPERIMENTS)

Digestion hours	Fractions					
	4-mesh	10-mesh	20-mesh	40-mesh	Filter paper	Filtrate
0	0	4.6	6.8	32.4	31.7	24.5
1	7.3	23.2	9.7	12.0	16.7	31.1
2	10.2	14.9	5.7	7.5	23.7	38.0
3	4.9	7.5	4.7	4.0	21.4	57.5

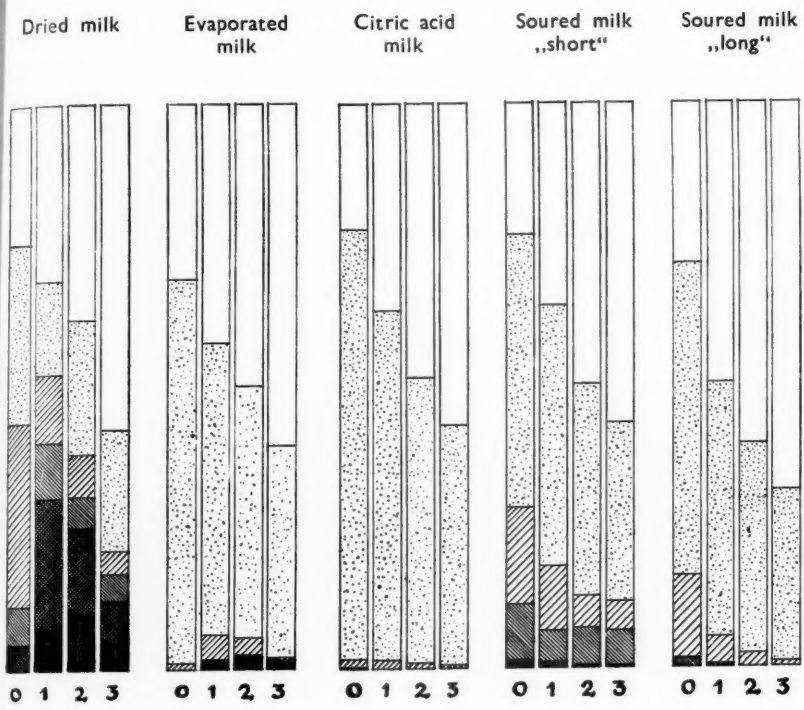

Fig. 3 Fig. 4

The zero time sample gives a very favorable impression of the digestibility of dried milk, but here the same phenomenon is noticed as with boiled milks: during the first hour coalescing of the curds still occurs, making the situation after one hour's digestion less favorable than with boiled milk. This is not surprising, as the spray-dried milk has been subjected to a rather mild heating. The casein curd of dried milk is, however, softer and flakier than the curd of boiled milks; this probably gives rise to the fact that after two hours' digestion, dried milk appears equal to boiled milks and after three hours it appears slightly superior to them.

Evaporated Milk

The evaporated milk used was also American. It was diluted by adding 1.2 parts of distilled water to 1 part of evaporated milk (86).

Results: Table 6 and Fig. 3.

TABLE 6

EVAPORATED MILK (5 EXPERIMENTS)

Digestion hours	Fractions					
	4-mesh	10-mesh	20-mesh	40-mesh	Filter paper	Filtrate
0	0	0	0	1.1	67.9	31.0
1	0	1.3	0.5	4.3	51.6	42.3
2	0.1	2.1	0.4	3.1	44.4	49.9
3	0	1.1	0.4	0.3	37.7	60.5

The result obtained with this milk is by far the most favorable of the results given by non-acid undiluted milks, and equal to those of acid milks. The size of the curd particle is of the same class as that of breast milk, as has been pointed out by many authorities (47, 125). Also here, traces of the coalescing tendency of the curds are seen during the first hour. It is surprising that in spite of the considerable heating included in the processing of this milk, the percentage of filterable nitrogen is already greater by zero time than in ordinary raw cow's milk. In the experiments of Doan and Dizikes, the amounts of filterable nitrogen in raw and evaporated milk, respectively, at zero time, were about equal.

Acid Milks

Of the »artificial» acid milks practically only citric acid milk (4.5 g of citric acid to 100 ml of milk) is used in Finland. The juice of citrus fruits is only occasionally obtainable here. Lactic acid milk has one serious handicap: concentrated lactic acid is a highly corrosive liquid, the drinking of which would cause severe lesions, and even its accidental application to the skin would be harmful. As cases of esophageal corrosion with caustic soda are deplorably common among the children in our country, it would seem unsafe to recommend another dangerous substance for common use.

In Finland country folk in particular have from time immemorial used bacterially soured milk, *piimä* or *viili*, as a nutriment. In Western and Northern Finland the souring takes place at a temperature of about 18° to 20° C and the product is ready for use in about 24 hours. The ferment consists in this case of a strain of *Streptococcus lactis*, in addition to which some other bacteria may grow in slight measure. The *piimä* is prepared by mixing into milk fresh from the cow and still warm a certain quantity of matured

piimä, about 5 to 10% of the total volume. As mentioned before, the lactic acid fermentation produced by the bacteria in question advances only to an acidity of about the isoelectric point of casein (about *p*H 4.5). At this reaction, the acid produced by these bacteria inhibits their own growth. A good *piimä* has an agreeable odor and flavor, the whey is not separated from the curd and there are no gas bubbles. — Climatic or other factors may cause an alteration of the *piimä*, i.e. a change of its bacterial composition so that it is no longer suitable for preparation of the next day's batch. In this case, a new »starter» is generally sought from some neigboring farm renowened for its good *piimä*.

If milk is allowed to sour spontaneously at the above mentioned temperature, the Escherichias and Aerobacters among them will grow well beside the *Streptococcus lactis*. However, after one day the *Str. lactis* is already the dominating species. If this milk is used for the inoculation of a new batch of milk, and a new passage then performed once every day, the bacteria population will after 3 or 4 days contain 99% of lactic acid streptococci. Whether the product thus formed is a good *piimä* depends in part upon whether suitable aroma bacteria (*Betacoccus cremoris Orla-Jensen*), also called *Leuconostoc citrovorum*, are present. — It is evident that with good luck this method may also be used for the replacing of a spoiled *piimä* ferment.

If a piece of cloth (usually linen) is soaked in the *piimä* and then dried, the ferment may be sent across long distances, as for instance to Finnish emigrants in the U.S.A.

It would seem probable that in the farms where *piimä* is made of new milk and where the taste of the population is sensitive towards changes in the quality of *piimä* the product thus prepared is relatively safe to be given even to young infants. It should be kept in mind that bovine tuberculosis has almost entirely disappeared from Finland, thanks to compulsory tuberculin testing of cattle and slaughtering of positively reacting cows. Also the contagious abortion (caused by *Brucella abortus*) is a very rare disease in Finland. — The above opinion on the feeding of *piimä* is, of course, applicable in the first place to households where a normal level of hygiene prevails; but on the other hand it is probable that in very unhygienic milieus any infant feeding mixtures may easily be contaminated between the boiling of the milk and the feeding.

In population centers, where nowadays commercial milk in

general already contains considerable quantities of germs, bacteria of, e.g. the Escherichia — Aerobacter group have had time to start multiplying rapidly. In these circumstances, the preparation of a first class, faultless *piimä* is not possible, except perhaps from sterilized milk. Thus, the *piimä* seems to be out of the question as a food for the infants in the population centers.

There are two types of the *piimä* of Western and Northern Finland: »short» *piimä* (*Streptococcus lactis*, the main variety) and »long» *piimä* [a variation producing ropiness, *Streptococcus lactis longi*; also named *Streptococcus piima* (100)]. In many places, the latter is preferred. In some places the original culture is obtained by soaking the leaves of certain herbs in water (e.g., in the islands off the coast of Uusimaa, Southern Finland (157).

In Eastern Finland another sour milk nutriment is found, the so-called *kokkelipiimä* which is in part prepared at a higher temperature; thus the bacteria involved are probably *Streptococcus thermophilus* and possibly some lactic acid bacilli.

In view of *piimä* being quite a common daily food in most of Finland in summertime, or even all the year round (Northern Finland) and as it has actually been fed with apparent success to infants of only 3—5 months of age, there seems to be reason to investigate the digestibility of this sour milk also.

CITRIC ACID MILK

Preparation. — 16 liters of milk are brought to boil; 800 grams of sugar are added a little before boiling point is reached. The milk container is cooled in iced water for 1½ to 2 hours. Seventy-two grams of citric acid are dissolved in about 2 deciliters of water and this solution added in small portions to the cold milk which is at the same time vigorously beaten with a whisk.

Results: Table 7 and Fig. 4.

TABLE 7

CITRIC ACID MILK (8 EXPERIMENTS)

Digestion hours	Fractions					
	4-mesh	10-mesh	20-mesh	40-mesh	Filter paper	Filtrate
0	0	0	0.3	1.5	75.9	22.3
1	0	0	0.2	1.4	61.8	36.6
2	0	0	0.1	1.0	50.5	48.4
3	0	0	0.1	0.6	42.4	56.9

The curd of citric acid milk is very fine and passes almost entirely through even the 40-mesh screen. The increase of filterable nitrogen is also relatively rapid, as e.g. in evaporated milk. The curd particles appear rounded and relatively firm, rather like grains of fine sand.

SHORT PIIMÄ

Preparation. — The bacterial culture was of the type used in dairies as a starter for souring the cream for butter-making. It was obtained from the laboratories of the Dairy Cooperative »Valio». This culture is a combination of pure cultures, namely, of *Streptococcus cremoris* (Orla-Jensen; held by some authorities to be only a variation of *S. lactis*); and a small amount of the »aroma bacteria» *Leuconostoc citrovorum*). Ten percent of this was added to the control milk used by the hospital (see under raw cow's milk) and the milk was allowed to stand at a temperature of 18 to 20° C for about 24 hours. The product had an agreeable flavor and was judged by several members of the hospital staff to be a good specimen of Finnish short *piimä*. The cream which had risen to the surface was mixed evenly into the *piimä* before use by beating with a fork.

Results: Table 8 and Fig. 4.

TABLE 8

SHORT PIIMÄ (5 EXPERIMENTS 0 HRS; 6 EXPERIMENTS 1, 2 AND 3 HOURS)

Digestion hours	Fractions					
	4-mesh	10-mesh	20-mesh	40-mesh	Filter paper	Filtrate
0	0	1.4	10.0	17.1	48.3	23.2
1	0	1.0	5.7	11.4	46.1	35.8
2	0	0.5	6.6	5.7	37.3	49.9
3	0	0.3	6.3	5.2	31.5	56.7

When acid milks are prepared by means of bacterial fermentation, the increase of acidity is the most gradual; thus it seems somewhat surprising that a part of the casein has formed relatively large particles. These are rounded and rather firm, in these respects similar to those in citric acid milk. The increase of soluble nitrogen is not, however, smaller than in citric acid milk. In any case, this milk variation also belongs to the easily digestible group.

LONG PIIMÄ

The culture was obtained from the Fish Market and had originated in the country. The product was in regard to appearance,

ropiness, flavor and odor a representative sample of Finnish long *piimä*.

Results: Table 9 and Fig. 4.

TABLE 9

LONG PIIMÄ (7 EXPERIMENTS)

Digestion hours	Fractions					
	4-mesh	10-mesh	20-mesh	40-mesh	Filter paper	Filtrate
0	0	0.1	1.6	14.4	55.3	28.6
1	0	0	0.5	4.9	45.0	49.6
2	0	0	0.2	2.2	37.4	60.2
3	0	0	0.1	0.9	30.2	68.8

The casein of long *piimä* forms a clearly finer curd than that of short *piimä*. Evidently the mucilage produced by the bacteria acts as a protective colloid. Accordingly, the curd particles appeared to be softer than in other acid milks. The rapid increase of filterable nitrogen should be noted; it would seem to be still more rapid than in citric acid milk. To judge from these *in vitro* experiments, long *piimä* should be the most easily digested kind of the cow's milks investigated here.

Dilutions of Cow's Milk

TWO-THIRDS-MILK

Preparation. — Wheat flour liquor: 330 grams of white wheat flour is mixed with a small amount of cold water to form a homogeneous paste; the rest of the water (total amount of water: 5,500 ml) is heated to boiling point and the flour paste added; this mixture is allowed to boil for 5 minutes, strained through a fine mesh and measured. If necessary, boiled water is added to make a total of 5,500 ml. It is allowed to cool.

14 liters of milk are brought to the boil and then left to cool to room temperature. After cooling, 2,100 ml of 50% sucrose solution and 4,900 ml of the above mentioned wheat flour liquor are added.

The $^2/_3$-milk thus prepared is the standard milk mixture recommended by physicians and Child Welfare centers in Finland for bottle-bed babies, from the age of 2 to 3 months up to 9 or 10 months.

Results: Table 10 and Fig. 5.

TABLE 10

TWO-THIRDS MILK (6 EXPERIMENTS)

Digestion hours	Fractions					
	4-mesh	10-mesh	20-mesh	40-mesh	Filter paper	Filtrate
0	1.8	12.1	23.9	20.9	17.1	24.2
1	2.4	6.7	9.9	19.9	28.1	33.0
2	1.2	4.5	9.3	10.3	27.6	47.1
3	0.5	1.7	0.8	2.5	28.4	66.1

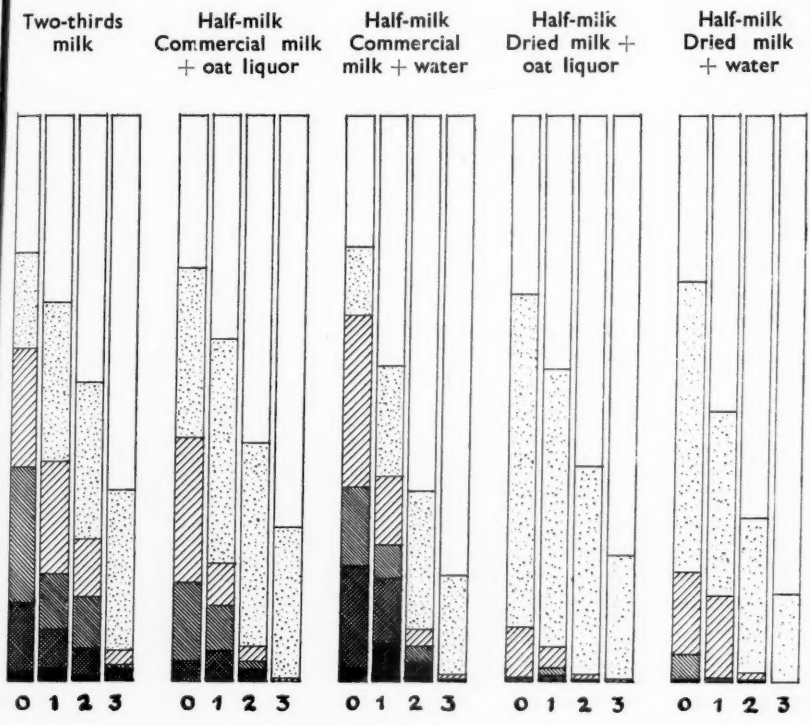
Two-thirds milk
Half-milk Commercial milk + oat liquor
Half-milk Commercial milk + water
Half-milk Dried milk + oat liquor
Half-milk Dried milk + water
0 1 2 3
0 1 2 3
0 1 2 3
0 1 2 3
0 1 2 3
Hours of digestion

Fig. 5

In the $^2/_3$-milk, the curd is influenced not only by bringing the milk to the boil but also by dilution and by a protective colloid effect. As is to be expected, the distribution of the curd particles is much more favorable than in the milk brought to the boil. The particles are also somewhat softer and more porous than those in

boiled milk, and would seem to offer less resistance to the action of the digestive mixture. After a digestion of three hours, almost the entire curd passes through the finest screen used.

THE HALF-MILKS

In Finland, physicians and Child Welfare centers have up to now recommended half-milk, diluted with oat gruel for the artificial feeding of infants below the age of 2 or 3 months. The preparation of gruel is tedious and time-consuming. Everywhere in the literature where this diluent is recommended, it is claimed that it brings about a finer curdling of the casein than if plain water were used; i.e., a protective colloid effect. It seemed to be of interest to investigate whether this would be demonstrable with the experimental method used, and how great the difference might be. — Experiments were performed a) starting from ordinary control milk and b) using reconstituted milk from the above mentioned milk powder.

Preparation of half-milk: Oat liquor: One hundred grams of rolled oats are added to 2,500 ml of cold water; the mixture is brought to the boil and allowed to simmer for 10 minutes, then strained through a fine mesh, measured and the volume made up to 2,500 ml with boiled water.

To 3,000 ml of milk, brought to the boil and cooled, 600 ml of 50% sucrose solution and 2,400 ml of the above described oat liquor are added.

Results: Table 11 and Fig. 5.

It will be noted that the addition of oat liquor distinctly reduces the size of curd particles in the zero hour samples; the same effect is still seen after one hour of digestion. However, after two and three hours respectively of digestion, no further difference in favor of the oat liquor diluent is found. On the contrary, the mixture diluted with water leads slightly as to the percentage of filterable nitrogen. The difference is not very great, but it is also found in the mixtures from dried milk as well as in the experiments performed with a smaller addition of hydrochloric acid. This would seem to indicate that this difference is significant.

The digestibility of reconstituted dried milk was much better than that of ordinary milk. Accordingly, the half-milk prepared from milk powder gives a much more favorable digestibility diagram than half-milk from ordinary milk. The effect on digestibility of the changes occurring during the preparation of dried milk is

TABLE 11

THE HALF-MILKS

Type of half-milk	Digestion hours	Fractions					
		4-mesh	10-mesh	20-mesh	40-mesh	Filter paper	Filtrate
Ordinary milk	0	0.0	3.6	13.9	25.6	30.0	26.9
+ oat liquor	1	0.0	5.3	8.1	7.4	39.7	39.5
(4 experi-	2	0.0	2.1	1.5	2.6	35.8	58.0
ments)	3	0.0	0.1	0.1	0.2	26.8	72.8
Ordinary milk	0	2.4	18.1	13.9	30.4	12.0	23.2
+ water	1	6.8	11.4	5.9	12.2	19.5	44.2
(4 experi-	2	0.9	2.2	3.1	3.0	24.4	66.4
ments)	3	0.0	0.0	0.4	0.8	17.6	81.2
Milk from	0	0.0	0.9	0.2	8.5	58.9	31.5
dried milk	1	0.0	1.1	1.3	3.7	49.0	44.9
+ oat liquor	2	0.0	0.4	0.1	0.7	36.8	62.0
(3 experi-	3	0.0	0.0	0.0	0.3	22.1	77.6
ments)							
Milk from	0	0.0	0.3	5.7	23.5	41.3	29.2
dried milk	1	0.0	0.1	0.5	14.6	32.7	52.1
+ water	2	0.0	0.4	0.2	1.0	27.4	71.0
(3 experi-	3	0.0	0.0	0.0	0.1	15.5	84.4
ments)							

much greater than the effect of the use of oat liquor as a diluent. Also in the half-milks from dried milk, there is a difference in favor of the oat liquor diluent in the zero and one hour samples; after two and three hours of digestion, the water-diluted mixture appears more favorable.

Experiments with a Reduced Amount of Hydrochloric Acid

As mentioned before, a half-hourly hydrochloric acid addition of 0.75 ml increases the acidity of the three-hour samples to values which are higher than those generally found in the stomachs of young children. Because of this, experiments were performed on some of the milks usually fed during the first months of life, using an addition of only 0.5 ml at a time.

Results: Table 12 and Figs. 6 and 7.

As expected, all milks are somewhat less digested than when more acid was used. The small number of the experiments on breast milk makes of course the results somewhat uncertain. The mutual

TABLE 12

EXPERIMENTS, WHERE THE HALF-HOURLY HCL ADDITION WAS 0.5 ML

Type of milk	Digestion hours	Fractions					
		4-mesh	10-mesh	20-mesh	40-mesh	Filter paper	Filtrate
Breast milk raw (double experiment)	0	0	0	0	0	66.8	33.2
	1	0	0	0	0	58.3	41.7
	2	0	0	0	0	14.9	85.1
	3	0	0	0	0	12.9	87.1
Breast milk brought to the boil (double experiment)	0	0	0	0	0	70.3	29.7
	1	0	0	0	0	62.4	37.6
	2	0	0	0	0	42.0	58.0
	3	0	0	0	0	32.4	67.6
Breast milk heated for 20 min. to 63° C (3 experiments)	0	0	0	0	0.1	59.0	40.9
	1	0	0	0	0	57.2	42.8
	2	0	0	0	0	42.2	57.8
	3	0	0	0	0	8.2	91.8
Mare's milk heated for 20 min. to 63° C (6 experiments)	0	0	0	0	0	58.7	41.3
	1	0	0	0	0	50.7	49.3
	2	0	0	0	0	43.4	56.6
	3	0	0	0	0	24.9	75.1
Citric acid milk (6 experiments)	0	0	0	0	3.1	72.6	24.3
	1	0	0	0	0.9	66.2	32.9
	2	0	0	0	0.4	52.9	46.7
	3	0	0	0	0.3	46.9	52.8
Half-milk from dried milk (oat liquor (4 experiments)	0	0	0.5	0.9	10.4	57.2	31.0
	1	0	0.0	0.2	5.6	39.9	54.3
	2	0	0.0	0.2	0.9	39.4	59.2
	3	0	0.1	0.5	0.4	29.2	69.9
Half-milk from dried milk (water) (4 experiments)	0	0	2.5	5.2	14.7	46.7	30.9
	1	0	0.5	5.1	13.8	24.0	56.6
	2	0	1.2	3.0	7.6	24.4	63.7
	3	0	0.1	0.4	1.5	21.9	76.1

order of the milks remains the same. Only the mare's milk gives a relatively less favorable diagram than in the previous experiments. — At the Children's Hospital of Helsinki it has been found that the composition of the mare's milk received there varied considerably, as it always was composed of the milk of only a few animals at a time and the individual milks differed much from each other; the same variation is known to occur among different breast milks.

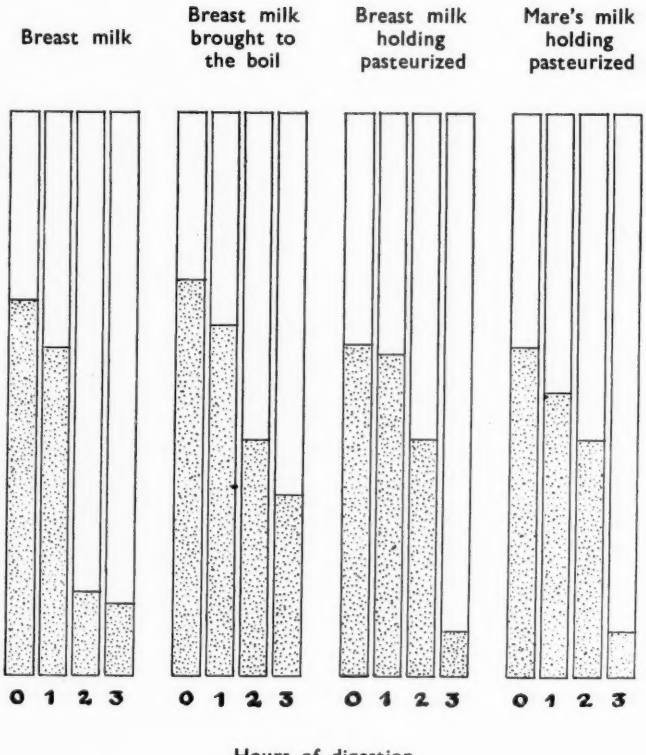

Fig. 6

Thus, no conclusions can be drawn from this difference in the behavior of mare's milk.

Comparison of the Effect of Oat Liquor as Diluent and the Effect of Boiling for Five Minutes

In the milk mixture formulae currently used in Finland it is advised to *bring the milk to the boil*, not to allow it to boil for more than a moment. The goal is to avoid a loss of thermolabile vitamins (ascorbic acid, thiamine).

Fresh cow's milk contains about 20 mg of ascorbic acid per liter. The amount decreases, however, rather rapidly. The decrease is accelerated by light, access of oxygen and the presence of copper ions (from badly tinned milk containers). Also there is in fresh milk an oxidase which acts upon the ascorbic acid; this enzyme is not markedly destroyed during a low temperature pasteurization.

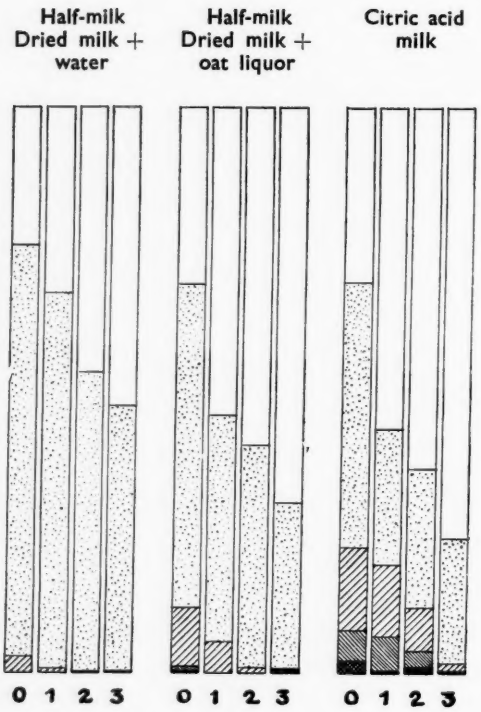

Fig. 7

In high temperature pasteurization it is destroyed, however; thus a milk so treated retains its ascorbic acid content better than raw or low temperature pasteurized milk (146). Pasteurisation in itself causes a loss of about one-third of the ascorbic acid contained in the milk (86).

The infant's daily need of ascorbic acid is estimated to be 20 to 50 mg, though already 10 mg per day suffices to prevent clinical scorbut (86). The principle put forward by Budin declares that an infant should never be given more than 0.6 liters of cow's milk per day. Thus, not even new milk would contain enough ascorbic acid to fulfill the infant's daily requirement. The ascorbic acid content of ordinary commercial milk usually approaches zero. It is evident that the infant's need for ascorbic acid must in any case for the main part be filled from other sources (fruit juices, scraped raw vegetables etc.)

The thiamine (vitamin B_1) content of cow's milk differs in

various analyses from 17 to 70 micrograms to each 100 ml. with the average value of about 38 micrograms to each 100 ml. Pasteurising or boiling for three minutes causes a loss of about 10 per cent. The requirement of the infant has been estimated at 150 micrograms daily (League of Nations standard, 1935) — also at 225 micrograms (U.S. Food and Drug Administration) or 400 micrograms (Food and Nutrition Board of the National Research Council, U.S.A.) Another statement gives the minimum as 30 micrograms for every 100 calories ingested. If the original milk has contained at least an average amount of thiamine the minimum requirements will be met with the customary milk mixtures. The 10% loss caused by pasteurizing or a short boiling does not essentially alter this fact. — The infant must at any rate obtain some kind of vitamin C supplement. If a natural »protective food» like fruit juice etc. is used, it will also provide a small additional amount of thiamine.

Thus considering the thiamine requirements of the infant it makes no essential difference whether the milk used for the milk mixtures is just brought to the boil or boiled for a short period of time.

Some twenty or thirty years ago, when early additions to the infant's diet of fruit juices and scraped raw vegetables was a completely strange notion to most mothers, it certainly was justified to recommend as short a heating of the milk as possible. Nowadays, when the public is maybe even too much »vitamin-minded» and the use of early fruit and vegetable additions has become a common practice, this probably is no longer so important. In order to be certain of the destruction of pathogenic germs, a five minutes boiling would be preferable. It has been demonstrated that a boiling of five minutes improves the digestibility of whole milk much more than only bringing to the boil. It seemed of interest to compare the digestibility of half milks, prepared from the same milk a) bringing the milk to boil, diluting with oat liquor and b) boiling for five minutes, diluting with water. If the effect of boiling were on the same level as that of oat gruel, the troublesome preparation of the latter could be omitted. With both milk mixtures, one double experiment was performe using a half-hourly addition of 0.75 ml of hydrochloric acid, and another using 0.5 ml.

Results: Tables 13 and 14 and Fig. 8.

TABLE 13

HALF-MILKS A) FROM MILK BROUGHT TO THE BOIL, DILUTED WITH OAT LIQUOR AND B) FROM MILK BOILED FOR FIVE MINUTES, DILUTED WITH WATER; HALF-HOURLY ADDITION OF HYDROCHLORIC ACID 0.75 ML

Type of milk	Digestion hours	Fractions					
		4-mesh	10-mesh	20-mesh	40-mesh	Filter paper	Filtrate
Milk brought to the boil + oat liquor (double experiment)	0	0	5.1	6.0	20.1	47.9	20.9
	1	0	10.4	9.6	14.7	27.6	37.7
	2	0	0	2.5	4.5	35.9	57.1
	3	0	0	0	0.3	25.7	74.0
Milk boiled for 5 min. + water (double experiment)	0	0	4.2	7.8	34.2	30.5	23.3
	1	0	6.6	16.3	21.3	16.9	38.9
	2	0	8.8	8.2	6.9	16.7	59.4
	3	0	0	0.2	0.7	22.1	77.0

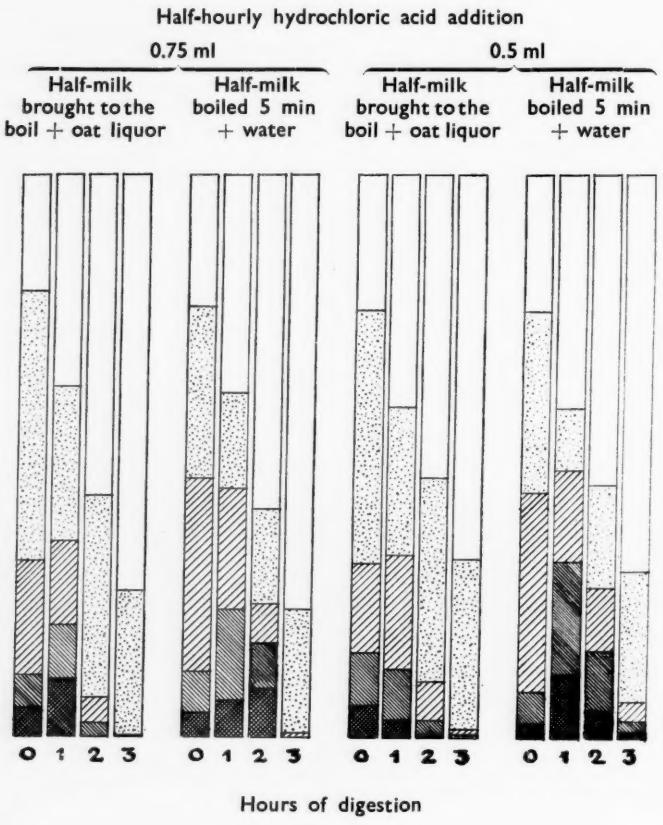
Half-hourly hydrochloric acid addition
0.75 ml
0.5 ml
Half-milk brought to the boil + oat liquor
Half-milk boiled 5 min + water
Half-milk brought to the boil + oat liquor
Half-milk boiled 5 min + water
0 1 2 3
0 1 2 3
0 1 2 3
0 1 2 3
Hours of digestion

Fig. 8

TABLE 14

HALF MILKS AS IN TABLE 13; HALF-HOURLY HCL ADDITION 0.5 ML

Type of milk	Digestion hours	Fractions					
		4-mesh	10-mesh	20-mesh	40-mesh	Filter paper	Filtrate
Milk brought to boil + oat liquor (double experiment)	0	0	5.8	9.4	15.8	44.9	24.1
	1	0	3.2	9.1	20.2	26.3	41.2
	2	0	0.6	2.5	6.9	36.2	53.8
	3	0	0	0.6	1.2	29.9	68.3
Milk boiled for 5 min. +water (double experiment)	0	0	2.7	5.5	35.7	32.0	24.1
	1	0	11.3	19.9	16.4	11.0	41.4
	2	0	4.6	11.2	10.9	18.3	55.0
	3	0	1.1	2.1	3.4	23.1	70.3

The experiments performed using both variations of the method gave similar results: At zero time, both milk mixtures appear about equal. During the first hour there occurs in the boiled milk, in spite of the dilution, a retarded coalescing of the curd particles; accordingly, this mixture appears less favorable after one hour of digestion. This difference is still discernible at two hours but after three hours of digestion it has practically disappeared. In the three hours samples, again a little difference in the filterable nitrogen (about 2% of the total nitrogen) in favor of the water diluted mixture may be noted.

Evaluation of Results

In the above experiments, different milks and milk mixtures have been digested in identical conditions and the different results have been noted. Nature follows another principle: with lesser or greater efforts the organism creates such conditions that the final result — in this case the nitrogen retention percentage — remains approximately constant. This would be very difficult to imitate in an experiment *in vitro*. It would seem probable that the results obtained by the method used here give an idea of the *relative* digestibility of these milks and milk mixtures, when compared with each other. As far as can be seen the results are in agreement with clinical experience.

From the point of view of digestibility breast milk and mare's milk form a class of their own, as may be expected of albumin milks. It should be noted that here the digestibility is measured by the changing of the protein into a finer particle size and into a filterable form. A titration of the amino acids would probably give a much poorer result, as the lactalbumin is at least in the conditions of the stomach broken down far less rapidly than casein (19). The effect of holding pasteurisation or boiling on the digestibility of breast milk is so slight, that it cannot explain the difference in clinical value claimed by many authors to exist between raw and heated breast milk. In the experiments performed by them, probably the storage of both parts of the milk (the part to be fed raw and the part to be boiled first) occurred in the same circumstances; thus the »storage» losses of vitamin C were equal. As the original vitamin C content of breast milk is stated to be around 50 mg per liter, a sufficient amount ought to remain even after a short heating. Rather one might think that the scarcity of vitamin B_1 in boiled breast milk might be harmful; it seems that even fresh breast milk contains only barely sufficient amounts of it, even if the mother's diet is adequate as to vitamin B_1. — Other explanations might be the destruction of the breast milk lipase and of eventual unknown »eutrophizing» factors by the heat.

The albumin of mare's milk is both experimentally *in vitro* and according to clinical experience easily digestible. The great disadvantage of this milk is its low fat content [maximally 2% (57); maximally 1.4% (87)] and the accordingly low calorific value. This may of course be corrected by adding a small amount of cream (from cow's milk) as has been done in the Children's Hospital of Helsinki. It is possible that mare's milk might prove useful in certain conditions, e.g. allergy to cow's milk.

Of undiluted cow's milks, the group next to breast milk as to digestibility is formed by evaporated milk and acid milks; this is also well in agreement with the good reputation of these milks in infant feeding. It is probably due to the excellent digestibility of the evaporated milk, that when using it, it is possible to disregard the widely accepted theory that the protein-to-carbohydrate ratio of cow's milk should be corrected by adding carbohydrate. McCulloch (101) has used as a standard feeding for infants evaporated milk diluted with only water; the relative amount of water was varied according to the age of the infants. Adams (1) has even used

for infants of all ages an evaporated milk, diluted with an equal volume of water, which means a milk still somewhat more concentrated than normal cow's milk.

In the present work it has not been attempted to investigate the digestibility of such dilutions of evaporated milk which are less concentrated than ordinary cow's milk. Evidently they would be more easily digestible than the reconstituted whole milk from evaporated milk. To judge from the relative digestibility of milk brought to the boil and the half-milk prepared from it, half milk from evaporated milk ought to perform nearly as well as breast milk.

Citric acid milk gives a digestibility diagram rather similar to that of evaporated milk. Evaporated milk requires a considerable secretion of hydrochloric acid. Citric acid milk facilitates considerably the work of the stomach but requires correspondingly more of the secretion of pancreatic and enteric juices and of bile. This is demonstrated by the fact that the alkaline reaction of the resting duodenum, is reached sooner after a meal of an acid milk mixture than after a »sweet» milk mixture (143, 144). — It would seem that both milks have their own special indications.

Of the two natural sour milks, long *piimä* was clearly more advantageous than short *piimä*. It is impossible to say whether it is just accidental that the long variety is the one more preferred in Finland.

The group next in digestibility consists of dried milk and the boiled milks. During the two first hours, the latter appear more advantageous, but during the third hour dried milk attains a better result. Dried milk seems to be better suited to the preparation of half-milk. — A boiling time of ten minutes does not essentially improve the digestibility as compared with five minutes; accordingly, the boiling time should not exceed five minutes. The least easily digested group contains the milk brought to the boil and the raw whole milk. Bringing to the boil improves markedly the digestibility of milk, but the improvement is far less than that caused by boiling. Keeping in mind the above quoted facts concerning the thermolabile vitamins, it would seem that if it is considered necessary to heat the milk intended for a certain infant, which in any case gives trouble and alters the flavor of the milk, the milk should be boiled and not just brought to the boil.

For dilutions of cow's milk, dried milk seems to be a more

advantageous basic material than boiled milk or milk brought to the boil. The advantage of oat liquor as a diluent is open to question; the difference in its favor found at the beginning of the experiment disappears as the digestion proceeds and the acidity increases. The three hours results would seem to indicate that oat liquor might contain some pepsin inhibiting factor. As stated earlier, it is also a matter of discussion whether the colloidal properties or the relatively slow hydrolysis and adsorbtion of the small amount of starch contained in the oat liquor are of any essential importance. The following conclusions would seem justified:

If ordinary fluid milk is used for infant feeding, either as such or as a mixture, it should be boiled for about five minutes. The quality of the original milk should, of cause, be high. In great population centers, to which the milk must be collected from a large area, there is during the hottest period of the summer a danger of the quality of milk sinking at least temporarily below the requirements of a milk for infants. Also, every year there are difficulties in the organizing of the sale of milk on Sundays. These difficulties would at least partly be overcome through the introduction of a pasteurized, aseptically bottled milk. In order to improve the digestibility, also this milk should be boiled for five minutes, as pasteurization does not alter the curdling properties of casein (86). Some kind of milk conserves: evaporated or dried milk, would also be needed, especially on journeys etc. Speaking in favor of evaporated milk its distinctly better digestibility may be mentioned, and the decrease of the antigenic properties of the lactalbumin caused by heating; also, a fluid is easier to measure accurately than a powder. On the other hand it does not keep in an opened can at room temperature any better than ordinary milk, while milk powder may be kept thus for long periods, though the oxydation of the milk fat gradually causes a rancid flavor. The losses in the vitamins C and B_1 are in milk powder on about the same level as in pasteurised milk; in evaporated milk they are about twice as high and loss of vitamin B_1 occurs still during the storing; thus, the vitamin B_1 content of evaporated milk may not be sufficient to provide the infant with its daily minimum dose.

If a choice must be made between these two, evaporated milk would seem to be more advantageous than dried milk.

In the country in circumstances where *piimä* is prepared from entirely fresh milk and the general hygiene of the household is

good, *piimä* — especially the long variety — would seem to be well suitable for infant feeding, the indications being the same as for undiluted acid milks in general. One dares not yet, however, make any public propaganda in its favor. Controlled infant feeding experiments with this national nutriment would be of considerable interest, even though the evaluation of such experiments is difficult as stated in the Introduction of this work.

The use of oat liquor as a diluent would not seem of importance as to the digestibility of the protein of milk. Its other possible advantages are outside the scope of this work.

Summary

An experimental method, which imitates the digestion process in an infant's stomach, has been used to investigate the digestibility of several milks and milk mixtures which are used in Finland for infant feeding.The decrease of the size of the casein curd particles and the increase of filterable nitrogen have been held to be criteria of the digestibility. The results have been given as per cents of the total nitrogen of the sample and are presented in the form of bar diagrams.

In the sense defined above the best digestible of the milks investigated are breast milk and mare's milk which give almost identical digestibility diagrams. The impairment of digestibility caused by holding pasteurisation or by the bringing to the boil of the breast milk is only slight.

Nearly as favorable findings as to the character of the casein curd are obtained with citric acid milk and long *piimä*. Short *piimä* forms slightly more coarse curds than these two. The digestibility diagrams of all these acid milks are also considered to be very favorable.

The heating of cow's milk improves its digestibility. Milk brought to the boil appears markedly better than raw milk but is clearly inferior to milk boiled for five or ten minutes. Between the two latter ones, there is no certain difference.

Dried milk is somewhat more easily digested than the boiled milks.

The two-thirds milk stands between dried whole milk and ordinary oat liquor half-milk.

In the preparation of half milk, dried milk is a much more

advantageous basic material than boiled milk or milk brought to the boil. Oat liquor causes a finer curdling of the casein than if only water is used as a diluent, but this difference gradually disappears during digestion; after three hours' digestion, oat liquor seems to have caused a slight disadvantage as to the percentage of filterable nitrogen.

If a good raw or pasteurised milk is used for infant feeding, it should be boiled for five minutes. If no such milk is available, conserved milks would be needed, of which evaporated milk appears somewhat more advantageous than dried milk.

The digestibility of the Finnish fermented sour milk *piimä* is very good and it ought to be, under certain circumstances, well suitable for infant feeding purposes.

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